EFFECTIVENESS OF ROCK PHOSPHATE AS A SOURCE OF PHOSPHORUS FOR PLANTS

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EFFECTIVENESS OF ROCK PHOSPHATE AS A SOURCE OF PHOSPHORUS FOR PLANTS[1]

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The relative effectiveness of rock phosphate as a fertilizer material in relation to the soil, crop, and climatic conditions of the Southeastern United States has been a controversial subject for many years. A review of published results by Rogers and others (20),[3] as well as more recent reports (4, 8, 10, 14, 15, 16, 17, 18), showed that per pound of phosphorus, raw phosphate was commonly less than one-half as effective as superphosphate. However, other results showed raw phosphate to be equally effective. Satisfactory explanations of these deviations were not possible from the results at hand. Particularly, no clear relationship had been established between soil characteristics and crop response to rock phosphate.

In an attempt to clarify this relationship, a series of uniform field experiments was initiated in several Southeastern States in 1953, together with supporting laboratory and greenhouse studies at Auburn, Ala.

The objectives of this study were: (1) To measure the relative effectiveness of rock phosphate as a source of phosphorus for forage crops on different soils, and (2) to relate rock phosphate availability to measureable soil characteristics.

FIELD EXPERIMENTS

Procedure

The field experiments, which were designed as complete randomized blocks with four replications, varied somewhat from one location to another but were planned to include the following treatments:

Source	P_2O_5 applied	When applied
	Lb./acre	
Concentrated superphosphate	15 30 60 120 300	Annually.
Rock phosphate	300 600	First year only.

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[3] Underscored numbers in parentheses refer to Literature Cited at the end of this report.

In some experiments additional treatments were included, such as a lime variable and combinations of rock phosphate and superphosphate. For all experiments, however, a phosphorus response curve was determined by use of a standard soluble source against which comparisons of response to rock phosphate could be made at equivalent yield levels (fig. 1).

The rock phosphate, concentrated superphosphate, and precipitated calcium sulfate used in all field experiments were provided from common lots of material that were stockpiled at the beginning of the study. Florida rock phosphate having the following characteristics was used:

Total P_2O_5	percent	33.5
Fluorine content	do	3.8
Citrate-soluble P_2O_5	do	3.0
Passing 100 mesh	do	73.2
Specific surface	$m.^2/g.$	22.4

The test crop in most experiments was white clover or ladino clover grown alone or in combination with a summer grass. In one experiment additional forage crops were included, and in one, alfalfa was substituted for the clover-grass mixture.

Fertilization with elements other than phosphorus was intended to maintain a sufficiently high level of these nutrients to eliminate the possibility of deficiency. The initial application of fertilizer was incorporated in the surface 3 to 4 inches of soil. Subsequent applications of maintenance fertilizer were applied broadcast on the surface.

Initial or treatment phase of the field study was 5 years, during which time annual applications of superphosphate were made at the various rates. During the sixth and seventh years, the residual effects of the previously applied phosphates on crop yields were measured.

Results

The yield results of the field experiments are recorded in appendix tables 20 to 31, and summarized in tables 1 to 5 and 7. In a number of experiments unfavorable climatic conditions or other factors resulted in such poor stands of the test crop that the results were not considered valid and are not reported. Also, since the early harvests coincided with the period of maximum clover growth and later clippings were predominantly grass or grass and weeds, the first clipping data are used in evaluating the availability of phosphorus to ladino clover. Results from two of the experiments were published earlier (10, 19), but the first clipping yields were not recorded. These data, therefore, are included here for comparison of the predominantly clover forage yield with the data from the other experiments of the regional study. Further, in several of the experiments that were originally a part of this study no response to phosphorus was found. Therefore, it was not possible to evaluate the effectiveness of rock phosphate in these experiments, and the results are not included in this report.

The results summarized in table 1 and plotted in figure 1 show that, as an average of all experiments, 23 and 30 pounds of P_2O_5 from superphosphate applied annually produced the same yield in the 5-year period as the 300- and 600-pound rate, respectively, from rock phosphate. The ratio of total phosphorus of rock phosphate to superphosphate required for equivalent yield was about 3:1 and 4:1 at the two rates.

The yields from rock phosphate relative to those from superphosphate are summarized in table 2. In all soils, rock phosphate was poorer or no better than superphosphate applied at equal or one-half the rate. This would approximate evaluation of rock phosphate on a comparable cost basis and at a commonly recommended rate of application for ladino clover. However, rock phosphate at 600 pounds of P_2O_5 was as effective as superphosphate at one-fourth the rate; it gave a higher clover yield on the Henry soil, and a lower yield on the Coxville, and was no different than superphosphate on the other five soils. Even at the 15-pound annual rate of superphosphate (75 pounds of P_2O_5 in 5 years), rock phosphate at 600 pounds, or eight times the superphosphate rate, produced a higher yield on only two soils and was no different on the others.

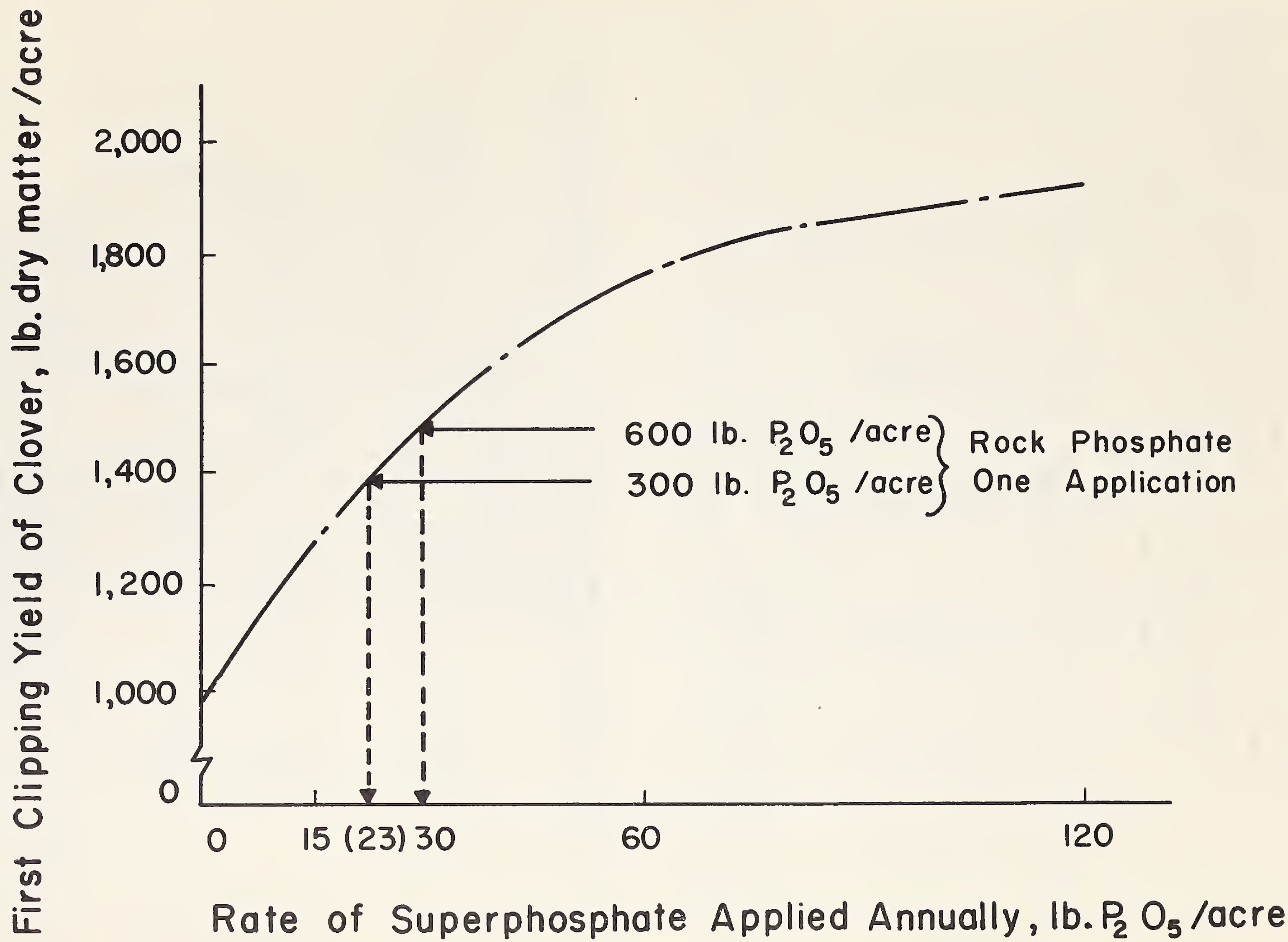

Figure 1.--Composite response curve of seven experiments and average yield from rock phosphate at two rates, illustrating method of evaluating rock phosphate in terms of superphosphate at same yield level.

Table 1.--First clipping yields of ladino clover produced by different annual rates of superphosphate and initial single applications of rock phosphate [1]

Soil	Dry matter yield of clover from source and rate of P_2O_5 indicated						
	Superphosphate					Rock phosphate	
	0	15	30	60	120	300	600
	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre
Wickham.......	999	(1,380) [2]	1,519	1,722	1,714	1,287	1,436
Henry..........	1,519	1,698	1,606	1,864	2,254	1,829	1,944
Rains..........	(1)	450	1,262	2,102	2,319	1,372	1,587
Wellston.......	1,086	1,569	1,553	1,557	1,739	1,388	1,290
Coxville.......	512	871	1,012	1,086	1,227	626	695
Leon..........	(1,100)	1,417	1,792	2,167	(2,400)	1,678	1,920
Boswell........	1,728	(1,775)	1,873	1,876	2,171	1,816	1,775
Average.....	992	1,309	1,517	1,790	1,975	1,449	1,521

[1] Results from experiments on Newtonia and Chewacla soils not included because of lack of response to phosphorus during treatment period.
[2] Values in parentheses are interpolated from individual response curves to fill in missing treatments.

Table 2.--Relative yields of ladino clover following a single application of rock phosphate compared with those from different rates of superphosphate applied over a 5-year period

Soil	Yield from rock phosphate relative to that from superphosphate applied at--			
	Equal [1] P_2O_5 rate	One-half [2] P_2O_5 rate	One-fourth [3] P_2O_5 rate	One-eighth [4] P_2O_5 rate
	Pct.	Pct.	Pct.	Pct.
Henry............	86	104	[5] 121	114
Leon.............	80	89	107	[5] 135
Wickham.........	[5] 84	[5] 83	95	[6] 104
Boswell..........	82	95	95	[6] 100
Wellston.........	[5] 74	83	83	82
Rains............	[5] 68	76	126	[5] 353
Coxville..........	[5] 57	[5] 64	[5] 69	80
Average.......	76	85	99	138

[1] Yield from 600 lb. of P_2O_5 as superphosphate applied over the 5-year period = 100.
[2] Yield from 300 lb. of P_2O_5 as superphosphate applied over the 5-year period = 100.
[3] Yield from 150 lb. of P_2O_5 as superphosphate applied over the 5-year period = 100.
[4] Yield from 75 lb. of P_2O_5 as superphosphate applied over the 5-year period = 100.
[5] Significantly different from yield from superphosphate.
[6] Interpolated values.

The base yields from superphosphate at the lower rates are far below maximum (table 2). Thus, the indicated equivalence of rock phosphate to superphosphate at one-fourth and one-eighth the rate is commonly at a low-yield level and should not be taken as indicating maximum yield from rock phosphate. In fact, maximum yield on most of these soils is improbable with any rate of rock phosphate. As shown in figure 1, the 300-pound application gave an average yield increase of 460 pounds, which was far below the average yield increase from an adequate level of phosphorus. Yet the addition of a second 300-pound increment of rock phosphate increased yield only another 80 pounds.

When a single initial application of superphosphate is compared with that of rock phosphate applied at the same and at twice the rate, the difference between sources is narrowed (table 3). Two of the experiments did not provide this comparison, but of the six that did, rock phosphate was still either inferior or no better than superphosphate. A single initial application of superphosphate was as effective in four of five soils as annual applications (table 4). One of the soils, Coxville, apparently had an unusually high ability to convert soluble phosphorus into a more difficulty available form, and the single application gave relatively poor yields on this soil.

Table 3.--Relative yields of ladino clover from single applications of rock phosphate compared with those from a single application of superphosphate

Soil	Number of years yields obtained	Relative yield from rock phosphate when applied at: [1]	
		300 lb. of P_2O_5	600 lb. of P_2O_5
		Pct.	Pct.
Rains	5	104	120
Wellston	5	95	88
Wickham	4	88	98
Boswell	3	84	82
Coxville	4	[2] 48	[2] 54
Average		84	95

[1] Yield from 300 lb. of P_2O_5 as superphosphate = 100.
[2] Significantly different from yield from superphosphate.

Table 4.--Relative yields of ladino clover following a single application of superphosphate compared with those from an equal amount of phosphorus from the same source applied in five annual increments

Soil	Number of years yields obtained	Relative yield from a single application[1]
		Pct.
Boswell	3	114
Rains	5	103
Wellston	5	95
Wickham	4	88
Coxville	4	[2] 48
Average		91

[1] At rate of 300 lb. of P_2O_5 per acre. Yield from equal amount of P_2O_5 applied in annual increments = 100.
[2] Significantly different from yield from annual application.

Some scientists consider the residual effect of rock phosphate to be an important point in favor of raw phosphate application. Since rock phosphate is commonly applied infrequently and superphosphate annually, residual effects of rock phosphate in the present study were evaluated during the first and second years following discontinuance of superphosphate application (table 5). The residual effect of rock phosphate was less or no different from that of superphosphate in all comparisons. The results in table 3 also provide insight into relative residual effectiveness of the two sources. During the 5-year period following single initial applications of both rock phosphate and superphosphate, rock phosphate was inferior to or no better than superphosphate even when the rock phosphate was applied at twice the rate of superphosphate. The soils fall into essentially the same order when ranked according to both residual effectiveness of rock phosphate and effectiveness during the treatment period. Thus, among soils representative of the Southeastern United States, the residual effect of rock phosphate is apparently not as great as that of superphosphate within the range of economically comparable rates.

The field results presented lead to the general conclusion that, although the effectiveness of rock phosphate varies widely among soils of the region, it is seldom more than one-fourth that of superphosphate applied at the same rate. Also, the residual effect of rock phosphate is generally poorer or no better than that of superphosphate applied at the same rate. These conclusions are in reasonable agreement with other published results. Harris (8), for example, found that superphosphate produced yields of whiteclover equal to or better than those produced with twice the rate of rock phosphate on a Bowie very fine sandy loam soil. Long (14) reported that yields in a four-crop rotation on three different southeastern soils were considerably lower from rock phosphate than from treated phosphate, even though the rock phosphate was applied at two or more times the rate of soluble phosphate. Similarly, Jones (12) concluded that rock phosphate applied at double the rate of P_2O_5 produced only 61 percent of the yield from superphosphate in pasture experiments in Mississippi.

The results presented here also show that there were clear and consistent differences among soils of the region in the effectiveness of rock phosphate as a source of phosphorus for plants. In one soil (Henry) rock phosphate was about as effective as superphosphate; in another soil (Coxville) it was no better than the zero phosphorus treatment; and in the others it ranged between

Table 5.--Relative yields of ladino clover during residual period from a single application of rock phosphate compared with those from equal amounts of phosphorus from superphosphate applied in five annual increments

Soil	Number of years yields obtained	Residual value of rock phosphate when applied at:	
		300 lb. P_2O_5 per acre [1]	600 lb. P_2O_5 per acre [2]
		Pct.	Pct.
Henry	2	114	93
Boswell	1	113	--
Newtonia	2	85	[3] 83
Wickham	2	82	101
Chewacla	2	80	84
Wellston	2	[3] 61	80
Rains	2	58	85
Average		85	88

[1] Yield from 60 lb. of P_2O_5 as superphosphate applied per acre annually = 100.
[2] Yield from 120 lb. of P_2O_5 as superphosphate applied per acre annually = 100.
[3] Significantly lower than yields from superphosphate.

these extremes. An explanation for these differences, however, is not possible from the information available. The final soil pH (table 6) may have been a factor inasmuch as the Henry was the most acid and the Coxville was the least acid of the group. The detailed results in the appendix tables do not support this suggestion, however. Yields on Coxville at three levels of lime show no effect for this variable. Other soil properties (table 6) apparently bear no relationship whatever to the order in which the soils are ranked in effectiveness of rock phosphate.

Lime did not significantly alter the relative effectiveness of rock phosphate in this study (table 7). Since it has been clearly shown (3, 5, 13) that rock phosphate availability increases with decreasing pH, the observed yields obviously reflect a balance between improved phosphorus availability and the appearance of other unfavorable conditions for plant growth at lower pH levels.

Table 6.--Some properties of the 0- to 6-inch layer of soils included in field studies of rock phosphate effectiveness

Soil type	Location	Initial pH	Limed pH	Predominant clay mineral[1]	Exchange capacity	Extractable P_2O_5	
						Dilute acid	Neutral NH_4F
					Meq./100 g.	P.p.m.	P.p.m.
Boswell very fine sandy loam...	Tuskegee, Ala.	5.0	5.7	K	2.1	32	52
Chewacla silt loam................	Clemson, S.C.	5.5	6.1	K, v	7.1	14	37
Coxville fine sandy loam.........	Summerville, S.C.	4.7	6.2	K, v	8.7	7	41
Henry silt loam......................	Oakley, Miss.	4.9	4.9	K, i	7.1	20	25
Leon fine sand........................	Gainesville, Fla.	4.8	5.5	I, m	5.7	24	20
Newtonia silt loam..................	Fayetteville, Ark.	5.3	5.7	I, K	5.8	24	23
Rains sandy loam....................	Tifton, Ga.	5.1	5.6	K, v	2.7	17	26
Wellston very fine sandy loam..	Blacksburg, Va.	5.0	5.9	V, I, K	4.5	10	24
Wickham fine sandy loam........	Camden, Ala.	5.3	5.6	K, m	13.5	32	51

[1] K = kaolinite, M = montmorillonite, I = illite, V = vermiculite. Lower case letters indicate very small percentages.

Table 7.--Effect of lime application on ladino clover yields when rock phosphate was the source of phosphorus

Soil	Number of years yields obtained	Relative clover yield without lime[1]
		Pct.
Wellston........................	5	115
Wickham........................	4	109
Chewacla.......................	2	100
Coxville.........................	4	97
Rains.............................	5	89
Boswell..........................	3	85
L.S.D. at 0.05	--	NS

[1] Yield with lime for each soil = 100.

GREENHOUSE AND LABORATORY EXPERIMENTS

Uniform Greenhouse Experiment

When the uniform field experiment was outlined, it was recognized that responses to treatments would be considerably influenced by climatic and other location factors. Location effects were evaluated by duplicating the key treatments of the field experiment in a greenhouse experiment at Auburn, Ala., in which ladino clover and sudangrass were grown as test crops on soils from all field locations. Any response differences among soils obtained in the greenhouse should be the result of inherent soil differences. Included in the experiment were soils from 16

field test locations as well as two soil types from Missouri and one from Illinois, which were included as reference soils from areas where rock phosphate has been used extensively by farmers.

All pots were limed to 75 percent of lime requirement with the exception of the treatment receiving 160 pounds of P_2O_5 from rock phosphate, which was tested with and without lime. Calcium carbonate was used as the source of lime, and it was mixed throughout the entire soil mass 3 months before planting. The soil was kept moist during the 3-month period to allow the lime to react with the soil.

The pots were planted to ladino clover and three harvests were obtained. The clover was followed by one crop of Tift sudangrass. All harvests were analyzed for total phosphorus so that uptake of phosphorus could be used along with yields as a measure of availability.

Yields and Phosphorus Uptake

Ladino clover.--The yield and phosphorus uptake data obtained from different rates of superphosphate show that most of the field test locations for ladino clover were deficient in phosphorus (table 8). From 1 to 18 pounds of P_2O_5 from rock phosphate were required to produce yields equal to those obtained from 1 pound of P_2O_5 from superphosphate. The average response to each source of phosphorus is shown in figure 2 for the 13 soils from the Southeast showing a response to superphosphate. Even at the most efficient rate of rock phosphate studied, about 6 pounds of P_2O_5 from rock phosphate was required to produce the same average yield as 1 pound from superphosphate. It is evident from the curves in figure 2 that maximum yields cannot be obtained with rock phosphate alone. There was little or no response to rock phosphate beyond the first increment of 80 pounds of P_2O_5.

Phosphorus uptake was calculated for all the soils in the uniform greenhouse experiment (table 8). All soils showed a response to superphosphate as measured by phosphorus uptake. Average phosphorus uptake for the 16 soils from the Southeast is shown in figure 3. Uptake from superphosphate increased with increasing rates of application, whereas uptake from rock phosphate did not change nearly as fast with increasing rate of application.

Evidently lime was critical for the production of clover since 160 pounds of P_2O_5 from rock phosphate produced as much or more clover with lime than without lime in 12 of the 19 soils. For the Dewey, Brenton, and Coxville soils, rock phosphate without lime produced considerably more clover than it did with lime. The total phosphorus uptake data showed a similar effect of lime on response to rock phosphate.

Sudangrass.--Yields and phosphorus uptake for one crop of sudangrass are given in table 9. Results for sudangrass show a higher relative availability for rock phosphate than do the results for ladino clover. By the time the sudangrass was planted, acidity of the soils had increased appreciably (see pH values at bottom of table 9). This increase in acidity may have favored rock phosphate over superphosphate for sudangrass. Since the phosphates were applied to ladino clover, the sudangrass was more a measure of residual effects. Because of differences in reaction of the two phosphates with soils, the availability of superphosphate very probably decreased with time, while that of rock phosphate remained about the same. This would result in an apparent increase in availability for rock phosphate relative to superphosphate.

Fertility Status of Soils

The pH, lime requirement, and extractable phosphorus content of the soils used in the uniform greenhouse experiment are presented in table 10. Most of the soils were moderately to strongly acid. Extractable phosphorus data indicate that most of the soils were medium to low in available phosphorus.

Table 8.--Availability of rock phosphate applied to soils from uniform rock phoshate field tests as measured by yields and phosphorus uptake of three cuttings of ladino clover grown in the greenhouse

P_2O_5 applied		Cecil sandy loam Watkinsville, Ga.		Dewey clay loam Greenville, Tenn.		Wickham fine sandy loam Camden, Ala.		Boswell very fine sandy loam Tuskegee, Ala.		Chewacla silt loam South Carolina	
Super-phosphate	Rock phosphate	Yield	P_2O_5 uptake	Yield	P_2O_5 uptake	Yield	P_2O_5 uptake	Yield	P_2O_5 uptake	Yield	P_2O_5 uptake
Lb/acre	Lb./acre	G.	Mg.	G.	Mg.	G.	Mg.	G.	Mg.	G.	Mg.
0	0	18.3	74.6	3.9	9.9	8.6	24.5	10.5	37.0	17.8	74.3
40	0	18.0	80.7	10.5	28.3	11.2	40.5	13.7	53.7	21.7	93.1
80	0	20.0	97.9	15.9	52.1	13.3	55.2	12.2	53.3	22.1	113.1
160	0	20.5	114.9	18.0	76.3	12.5	65.0	14.3	69.7	23.2	133.1
0	80	19.3	81.1	4.0	11.8	10.2	38.2	10.6	37.5	18.6	80.2
0	160	19.3	83.2	4.9	11.7	11.7	44.2	10.4	42.1	19.3	88.9
0	320	18.8	81.9	7.3	25.4	10.3	46.9	11.8	50.9	19.4	93.4
0	[1] 160	17.1	77.7	15.3	56.2	10.4	41.8	9.3	35.1	18.5	93.3
pH of unlimed soil..........		5.2	--	5.4	--	5.3	--	5.0	--	5.6	--
L.S.D. at 0.05..............		2.12	10.20	1.56	13.66	1.43	5.90	2.99	13.86	1.70	11.36
L.S.D. at 0.01..............		2.88	13.89	2.12	18.59	1.94	8.03	4.06	18.87	2.31	15.46
C.V.........................		7.7	8.0	10.5	28.2	9.3	9.0	18.9	19.3	5.8	8.1

P_2O_5 applied		Leon fine sand Florida		Plummer sandy loam Tifton, Ga.		Alcoa silt loam Knoxville, Tenn.		Brenton silt loam Urbana, Ill.		Newtonia silt loam Arkansas	
Super-phosphate	Rock phosphate	Yield	P_2O_5 uptake	Yield	P_2O_5 uptake	Yield	P_2O_5 uptake	Yield	P_2O_5 uptake	Yield	P_2O_5 uptake
Lb./acre	Lb./acre	G.	Mg.	G.	Mg.	G.	Mg.	G.	Mg.	G.	Mg.
0	0	12.1	42.3	1.9	4.8	7.3	21.2	9.3	27.9	10.9	33.6
40	0	13.2	67.4	7.3	23.3	11.7	42.7	13.8	51.4	16.1	59.6
80	0	12.8	81.2	8.4	32.0	14.2	56.9	15.3	68.8	19.4	83.4
160	0	13.4	126.4	10.2	43.3	16.0	85.3	15.4	79.0	19.3	92.5
0	80	12.3	47.3	3.3	8.8	9.9	29.7	9.3	32.1	15.1	46.1
0	160	14.1	60.0	4.8	13.2	8.5	28.7	8.9	31.5	15.9	48.6
0	320	14.2	71.9	5.7	17.8	10.0	35.6	11.5	42.1	16.5	59.3
0	[1] 160	9.4	100.5	2.7	10.5	9.1	31.9	15.3	71.6	15.5	110.9
pH of unlimed soil..........		4.8	--	5.1	--	5.4	--	5.4	--	5.4	--
L.S.D. at 0.05..............		1.67	20.38	1.82	7.00	1.74	7.16	2.15	11.04	1.49	9.06
L.S.D. at 0.01..............		2.27	27.74	2.48	9.53	2.38	9.75	2.92	15.02	2.03	12.33
C.V.........................		8.9	18.8	22.4	24.3	11.0	13.8	11.8	14.7	6.9	8.6

P_2O_5 applied		Wellston very fine sandy loam Virginia		Mayhew silty clay loam Pontotoc, Miss.		Lloyd clay loam Gold Hill, Ala.		Coxville fine sandy loam South Carolina	
Super-phosphate	Rock phosphate	Yield	P_2O_5 uptake	Yield	P_2O_5 uptake	Yield	P_2O_5 uptake	Yield	P_2O_5 uptake
Lb./acre	Lb./acre	G.	Mg.	G.	Mg.	G.	Mg.	G.	Mg.
0	0	8.4	23.9	20.5	78.2	25.8	116.0	3.3	9.5
40	0	13.4	44.5	26.8	115.2	25.6	115.3	8.6	27.7
80	0	14.8	53.4	26.0	121.0	29.2	131.7	11.9	42.1
160	0	13.9	56.2	29.3	144.5	25.4	152.9	14.1	55.4
0	80	9.2	27.9	24.9	97.9	24.9	109.3	6.1	10.0
0	160	10.1	32.6	25.0	104.8	24.0	97.7	4.6	13.0
0	320	11.6	38.6	27.4	125.6	25.2	109.9	5.6	16.8
0	[1] 160	9.4	40.4	23.8	113.5	26.0	117.5	9.2	31.0
pH of unlimed soil..................		5.0	--	4.8	--	6.1	--	5.0	--
L.S.D. at 0.05......................		2.66	10.95	3.26	12.18	2.46	21.12	1.23	5.29
L.S.D. at 0.01......................		3.63	14.91	4.44	16.58	3.35	28.75	1.68	7.19
C.V.................................		15.7	18.5	8.8	7.4	6.3	12.2	11.0	13.8

P_2O_5 applied		Henry silt loam Oakley, Miss.		Menfrow silt loam Weldon, Mo.		Putnam silt loam Missouri		Crockett clay Brooksville, Miss.		Bladen clay loam Fleming, Ga.	
Super-phosphate	Rock phosphate	Yield	P_2O_5 uptake	Yield	P_2O_5 uptake	Yield	P_2O_5 uptake	Yield	P_2O_5 uptake	Yield	P_2O_5 uptake
Lb./acre	Lb./acre	G.	Mg.	G.	Mg.	G.	Mg.	G.	Mg.	G.	Mg.
0	0	14.1	51.5	18.2	81.7	17.3	71.8	18.9	83.9	3.8	8.8
40	0	17.6	77.3	23.8	120.6	21.5	109.5	20.7	98.3	12.2	36.8
80	0	19.8	90.5	19.5	99.8	22.1	128.7	22.4	114.6	15.4	57.1
160	0	21.7	113.6	24.0	134.6	23.1	144.0	23.0	131.4	16.5	74.1
0	80	18.0	73.8	21.1	101.6	20.1	92.4	20.0	87.6	6.9	18.2
0	160	17.8	78.5	21.9	105.8	20.6	100.2	19.8	88.7	9.3	25.5
0	320	18.8	85.2	21.2	105.4	20.5	101.7	19.7	93.3	12.6	39.8
0	[1] 160	16.6	75.4	21.1	110.2	21.5	108.9	20.0	102.1	8.1	42.9
pH of unlimed soil		5.4	--	5.7	--	5.9	--	5.8	--	4.8	--
L.S.D. at 0.05................		2.48	18.89	3.43	18.14	2.23	12.85	1.90	11.55	3.33	6.81
L.S.D. at 0.01................		3.38	25.71	4.66	24.69	3.04	17.49	2.59	15.72	4.53	9.26
C.V...........................		9.3	16.2	10.8	11.4	7.2	8.2	6.3	7.9	20.7	12.0

[1] Unlimed. All other treatments limed to 75 percent of lime requirement.

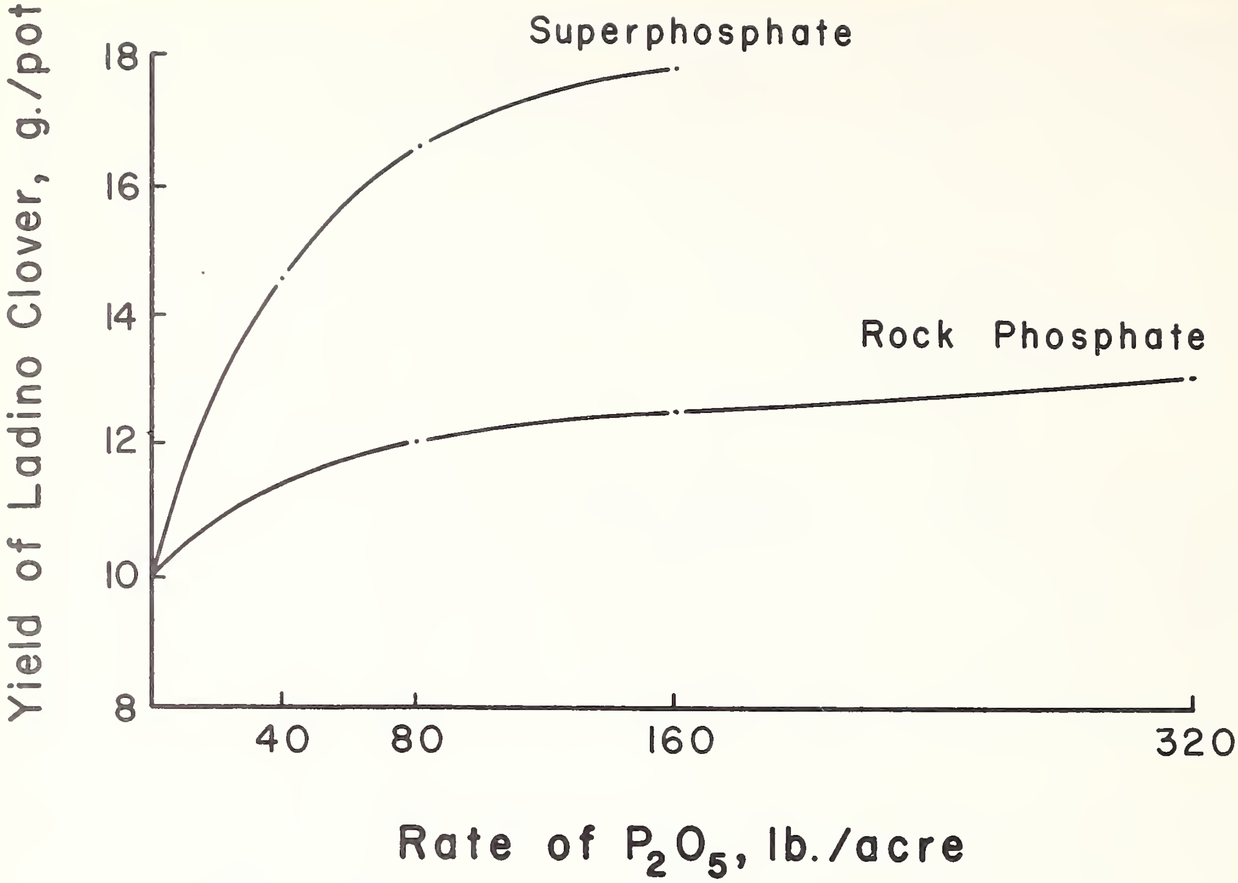

Figure 2.--Average response of ladino clover in the greenhouse to rock phosphate and superphosphate for 13 soils from the Southeast.

Residual Phosphorus Greenhouse Experiment

The residual phase of the field experiment was begun on soils obtained from key treatments at 11 locations. Sufficient soil was collected from the check plots at each location for a phosphorus response curve for which concentrated superphosphate was used as the standard. The soil was brought to Auburn, Ala., where residual effects could be studied in the greenhouse under a uniform environment. The pots were arranged in the greenhouse in a randomized block design and each treatment was replicated four times. Ladino clover was used as the test crop. If the pH of the soil from the limed treatments was below 5.0, sufficient dolomitic lime was applied to meet the requirements of ladino clover for a short time. The rate of lime applied was low to make conditions as near optimum as possible for rock phosphate availability.

Yields and Phosphorus Uptake

Yields and phosphorus uptake of ladino clover grown on the 11 soils are presented in table 11. Nine of the soils showed a yield response to freshly applied superphosphate, and seven soils showed a response to residual superphosphate. Based on phosphorus uptake, all soils responded to freshly applied superphosphate as well as to residually applied superphosphate.

The 300-pound rate of P_2O_5 from superphosphate applied the first year only was included in the field experiment to compare residual effects (1) with an equivalent amount of superphosphate applied annually during the 5-year period and (2) with rock phosphate applied the first year only.

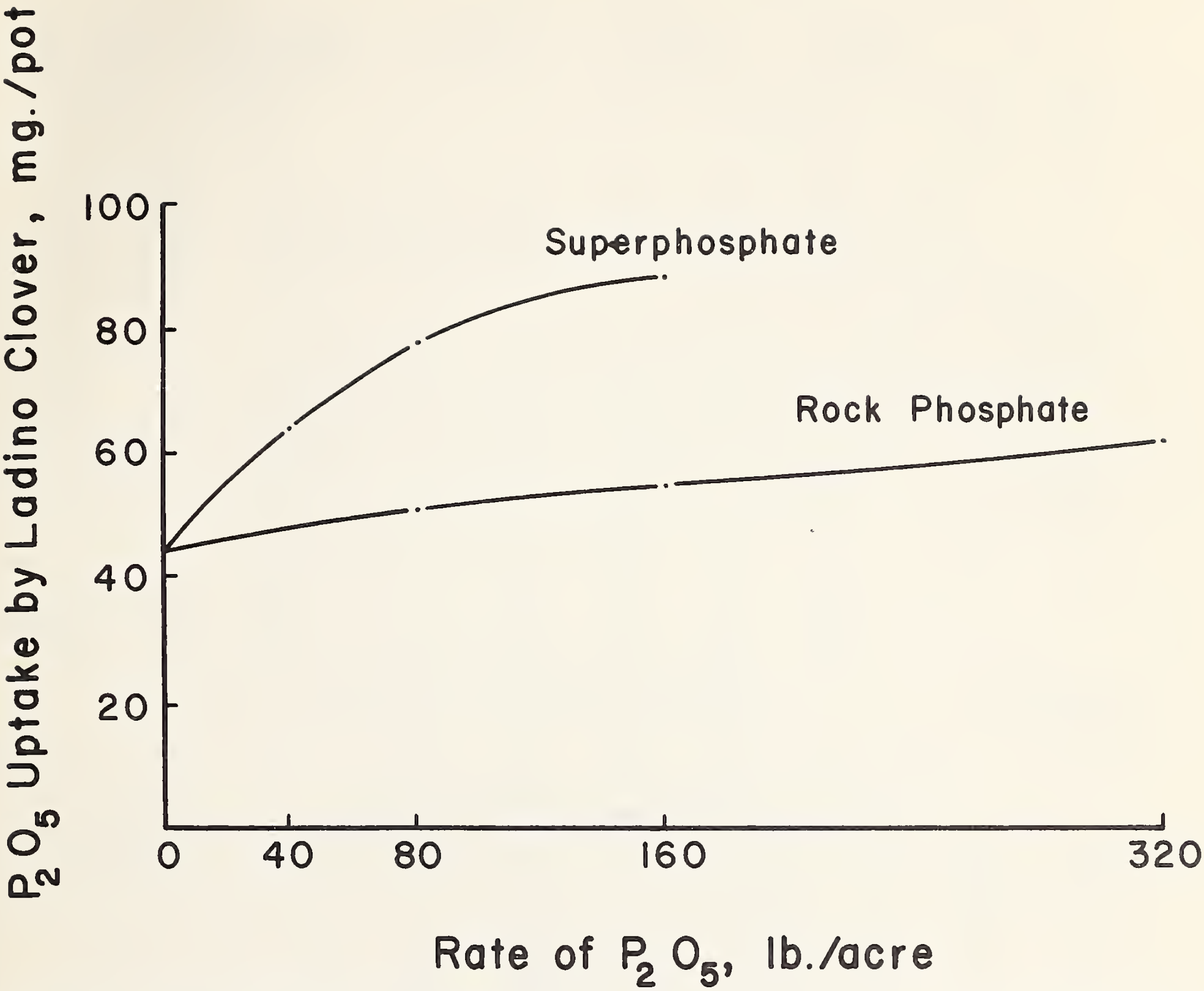

Figure 3.--Average phosphorus uptake by ladino clover in the greenhouse for 16 Southeast soils treated with rock phosphate and superphosphate.

Of the nine soils where this comparison was included, yields were lower for the treatment that received 300 pounds of P_2O_5 from superphosphate the first year only as compared with that for the treatment of 60 pounds of P_2O_5 annually. Based on phosphorus uptake, five of the nine soils showed less residual value for the 300-pound rate the first year only as compared with that for 60 pounds annually for 5 years.

Residual effects of rock phosphate were obtained on six of the nine soils that gave a yield response to freshly applied superphosphate. Based on phosphorus uptake, eight soils showed residual effects of rock phosphate. The effect of lime on residual value of rock phosphate was not pronounced. Lime decreased yields and phosphorus uptake from rock phosphate on Coxville fine sandy loam but increased yields from rock phosphate on Wickham fine sandy loam. On the remaining soils, lime had no effect on availability of rock phosphate.

In general the residual effects of rock phosphate were less than those from an equivalent amount of P_2O_5 from superphosphate applied annually in a 5-year period. However, on two soils, Henry silt loam and Leon fine sand, the residual effects of rock phosphate were equal to those of superphosphate applied on an equivalent P_2O_5 basis.

Table 9.--Availability of rock phosphate applied to soils from uniform rock phosphate field tests as measured by yields and phosphorus uptake of sudangrass grown in the greenhouse

P_2O_5 applied		Cecil sandy loam Watkinsville, Ga.		Dewey clay loam Greenville, Tenn.		Wickham fine sandy loam Camden, Ala.		Boswell very fine sandy loam Tuskegee, Ala.		Chewacla silt loam South Carolina	
Superphosphate	Rock phosphate	Yield	P_2O_5 uptake	Yield	P_2O_5 uptake	Yield	P_2O_5 uptake	Yield	P_2O_5 uptake	Yield	P_2O_5 uptake
Lb./acre	Lb./acre	G.	Mg.	G.	Mg.	G.	Mg.	G.	Mg.	G.	Mg.
0	0	10.1	29.7	3.6	7.2	5.9	16.0	3.4	9.6	8.7	20.9
40	0	10.0	34.2	6.3	11.4	6.4	17.7	5.4	15.4	10.3	27.5
80	0	9.9	31.3	9.3	17.2	8.8	21.9	8.9	26.6	10.9	33.0
160	0	9.7	34.4	12.4	30.9	9.3	28.9	9.7	30.7	12.5	37.0
0	80	10.3	30.3	5.0	9.5	7.4	20.2	5.0	16.9	9.5	25.4
0	160	9.8	33.0	5.9	12.7	9.0	25.9	5.8	18.5	10.7	29.1
0	320	9.3	34.4	8.8	20.3	9.9	31.8	6.0	21.8	10.1	33.2
0	[1] 160	8.5	32.9	10.9	28.8	8.8	25.9	6.8	24.5	10.1	32.3
pH of limed soil after sudangrass harvest..........		5.0	--	5.1	--	4.8	--	4.9	--	4.9	--
L.S.D. at 0.05..............		1.48	5.58	1.80	5.21	1.31	3.73	1.82	4.67	1.66	3.29
L.S.D. at 0.01..............		2.02	7.60	2.45	7.09	1.79	5.08	2.48	6.36	2.26	4.48
C.V.........................		10.3	11.7	15.7	20.5	10.9	10.8	19.5	15.5	10.9	8.8

P_2O_5 applied		Leon fine sand Florida		Plummer sandy loam+ Tifton, Ga.		Alcoa silt loam Knoxville, Tenn.		Brenton silt loam Urbana, Ill.		Newtonia silt loam Arkansas	
Superphosphate	Rock phosphate	Yield	P_2O_5 uptake	Yield	P_2O_5 uptake	Yield	P_2O_5 uptake	Yield	P_2O_5 uptake	Yield	P_2O_5 uptake
Lb./acre	Lb./acre	G.	Mg.	G.	Mg.	G.	Mg.	G.	Mg.	G	Mg.
0	0	4.5	6.3	1.3	2.5	3.4	9.3	5.7	12.5	6.0	15.7
40	0	9.1	16.4	4.7	9.4	5.1	11.0	7.6	15.3	8.0	19.5
80	0	10.5	30.2	7.6	19.3	6.8	13.3	8.2	18.6	7.6	21.2
160	0	10.1	60.0	8.6	23.5	9.3	19.0	9.4	26.7	11.3	33.0
0	80	9.7	19.1	2.0	4.4	5.0	11.5	4.8	13.2	8.1	21.5
0	160	10.4	30.7	4.2	9.9	5.0	11.5	5.2	15.6	7.4	22.1
0	320	9.8	39.3	5.7	14.2	5.5	13.9	5.5	21.0	8.9	28.0
0	[1] 160	7.6	55.8	1.9	6.5	4.5	11.6	10.1	26.0	7.7	29.0
pH of limed soil after sudangrass harvest..........		4.6	--	4.6	--	4.8	--	5.2	--	5.2	--
L.S.D. at 0.05..............		1.69	9.51	1.48	4.24	1.37	2.92	2.53	3.49	1.74	1.26
L.S.D. at 0.01..............		2.30	12.94	2.02	5.78	1.86	3.98	3.44	4.75	2.37	1.71
C.V.........................		12.8	19.5	22.3	25.7	16.7	16.0	22.0	12.6	14.5	3.6

P_2O_5 applied		Wellston very fine sandy loam Virginia		Mayhew silty clay loam Pontotoc, Miss.		Lloyd clay loam Gold Hill, Ala.		Coxville fine sandy loam South Carolina	
Superphosphate	Rock phosphate	Yield	P_2O_5 uptake	Yield	P_2O_5 uptake	Yield	P_2O_5 uptake	Yield	P_2O_5 uptake
Lb./acre	Lb./acre	G.	Mg.	G.	Mg.	G.	Mg.	G.	Mg.
0	0	3.1	6.7	10.0	29.2	6.0	20.9	1.7	5.0
40	0	6.5	12.5	10.9	31.9	6.0	22.1	2.6	5.0
80	0	7.3	17.0	10.6	36.1	7.1	26.2	3.9	7.1
160	0	9.3	25.1	11.5	43.6	8.1	31.7	5.6	12.9
0	80	3.8	9.8	10.4	28.7	7.2	27.8	2.1	5.2
0	160	4.8	14.4	11.3	35.2	6.8	24.9	2.1	4.1
0	320	6.0	17.0	10.8	37.4	6.8	25.6	2.5	5.1
0	[1] 160	4.4	16.6	9.3	32.7	6.1	22.9	2.9	5.7
pH of limed soil after sudangrass harvest..............		4.5	--	4.8	--	5.7	--	4.9	--
L.S.D at 0.05....................		1.85	5.44	2.55	5.51	1.18	5.17	1.31	7.92
L.S.D. at 0.01..................		2.52	7.40	3.47	7.51	1.61	7.04	1.78	10.79
C.V.............................		22.0	24.8	16.4	10.9	11.8	14.0	30.8	29.0

P_2O_5 applied		Henry silt loam Oakley, Miss.		Menfrow silt loam Weldon, Mo.		Putnam silt loam Missouri		Crockett clay Brooksville, Miss.		Bladen clay loam Fleming, Ga.	
Superphosphate	Rock phosphate	Yield	P_2O_5 uptake	Yield	P_2O_5 uptake	Yield	P_2O_5 uptake	Yield	P_2O_5 uptake	Yield	P_2O_5 uptake
Lb./acre	Lb./acre	G.	Mg.	G.	Mg.	G.	Mg.	G.	Mg.	G.	Mg.
0	0	4.6	11.9	9.2	28.6	8.3	19.4	6.5	16.4	0.7	1.4
40	0	6.3	15.2	11.0	31.3	10.9	25.9	7.8	21.2	2.2	3.8
80	0	8.6	20.1	10.9	35.8	11.3	29.3	8.2	22.2	4.8	8.5
160	0	8.6	23.4	13.6	41.3	12.6	37.9	10.5	29.1	8.0	22.4
0	80	7.7	18.9	11.4	34.0	10.0	27.9	6.6	18.1	1.4	2.8
0	160	8.0	21.2	10.9	31.9	10.3	27.4	6.0	18.8	3.0	6.0
0	320	9.7	24.8	12.8	33.5	11.6	30.4	7.4	21.3	5.1	11.1
0	[1] 160	7.9	17.3	11.3	35.9	11.1	27.7	9.1	25.9	0.1	--
pH of limed soil after sudangrass harvest..........		4.6	--	5.2	--	5.2	--	5.2	--	4.6	--
L.S.D. at 0.05..............		2.20	3.92	2.59	6.40	1.91	5.44	1.95	3.73	4.03	2.56
L.S.D. at 0.01..............		3.00	5.83	3.52	8.72	2.61	7.40	2.66	5.08	5.49	3.49
C.V.........................		19.5	13.9	15.4	12.8	17.1	13.1	17.1	11.7	8.6	25.0

[1] Unlimed. All other treatments limed to 75 percent of lime requirement.
+ Has been reclassified as "Rains sandy loam."

Table 10.--Fertility status of soils used in uniform greenhouse experiment

Soil type	Location	pH	Lime requirement	P_2O_5 extracted by--			
				Dilute acid	Neutral NH_4F	HCl-NH_4F	Anion exchange resin
			Lb/acre	P.p.m.	P.p.m.	P.p.m.	P.p.m.
Wickham fine sandy loam	Camden, Ala.	5.3	2,950	11	27	288	9.9
Boswell very fine sandy loam	Tuskegee, Ala.	5.5	1,550	32	38	145	7.1
Lloyd clay loam	Gold Hill, Ala.	6.1	2,050	34	65	291	24.1
Cecil sandy loam	Watkinsville, Ga.	5.2	1,500	110	77	179	21.3
Bladen clay loam	Fleming, Ga.	4.8	5,500	5	21	38	12.8
Plummer sandy loam+	Tifton, Ga.	5.1	1,500	6	10	10	5.7
Coxville fine sandy loam	South Carolina	5.6	1,800	10	42	198	11.3
Chewacla silt loam	South Carolina	5.0	5,450	14	46	200	18.4
Leon fine sand	Gainesville, Fla.	4.8	3,050	7	13	16	29.8
Alcoa silt loam	Knoxville, Tenn.	5.4	3,750	18	46	170	12.8
Dewey clay loam	Greenville, Tenn.	5.4	2,500	14	20	48	9.9
Newtonia silt loam	Fayetteville, Ark.	5.4	1,600	22	27	112	11.3
Henry silt loam	Oakley, Miss.	5.4	1,900	20	32	218	12.8
Mayhew silty clay loam	Pontotoc, Miss.	4.8	3,750	73	142	330	39.7
Crockett clay	Brooksville, Miss.	5.8	2,200	34	50	166	25.5
Wellston very fine sandy loam	Blacksburg, Va.	5.0	2,050	14	26	96	8.5
Brenton silt loam	Urbana, Ill.	5.4	4,550	34	45	198	12.8
Menfrow silt loam	Weldon, Mo.	5.7	2,250	80	78	253	35.5
Putnam silt loam	Missouri	5.9	1,600	67	46	237	25.5

+ Has been reclassified as "Rains sandy loam."

Extractable Phosphorus and pH of Soils

The soils used in the residual phosphorus study in the greenhouse were classified with respect to extractable phosphorus and pH (table 12). The extractions show that considerable phosphorus had accumulated. Since the forms of accumulated phosphorus resulting from superphosphate and rock phosphate may be quite different, the extractants used were selected because they tend to be selective in dissolving certain forms of phosphorus. For example, dilute acid readily dissolves calcium phosphates, but is not very effective in dissolving iron and aluminum phosphates. Just the opposite is true for the dissolving action of neutral ammonium floride. The amount of phosphorus released to an anion exchange resin is related to the total water-soluble phosphorus present in the soil.[4]

In seven of the nine soils where a comparison could be made, soils that had received 60 pounds of P_2O_5 annually for 5 years contained more extractable phosphorus by each of the four methods used than did soils that had received 300 pounds of P_2O_5 from superphosphate the first year only. This is in line with yields that were higher where 60 pounds of P_2O_5 annually had been applied as compared with yields from 300 pounds applied the first year only. For most soils neutral ammonium fluoride extracted considerably less phosphorus from rock phosphate-treated soils than it did from soils that had received the same amount of P_2O_5 from superphosphate. This indicates that much of the rock phosphate had not reacted with the soils.

Most of the rock phosphate treatments that had been limed were lower in neutral ammonium fluoride-soluble phosphorus than the rock phosphate treatments that had not been limed. This indicates that liming had reduced the reaction between rock phosphate and soil. Liming also reduced the amount of anion resin-extractable phosphorus from soils treated with rock phosphate.

Evaluation of Sources of Rock Phosphate

Many field and greenhouse tests have been conducted to evaluate the effectiveness of rock phosphate for crop production. The results have varied considerably, depending upon the test conditions. In many of these tests different sources of rock phosphate were used whose chemical and physical properties varied widely. In the present study these properties were evaluated under uniform conditions for seven different sources so that their effectiveness in crop production might become more predictable.

Classification of Rock Phosphate Sources

Although the seven sources of rock phosphate were ground to pass a 100-mesh sieve, they varied a great deal in specific surface as well as in their solubility in sequestrene, lactic acid, and neutral ammonium citrate solutions (table 13). South Carolina and foreign sources were much more soluble than Idaho, Tennessee, and Florida sources.

Rock phosphate deposits vary considerably as to their physical and chemical properties (1, 2, 9, 11). Hendricks and others (9) examined a number of phosphates by microscopic and X-ray diffraction methods and reported that phosphate rock from the United States consisted mainly of submicrocrystalline fluorapatite, $Ca_{10}F_2(PO_4)_6$, whereas the phosphates of Christmas, Nauru, and Ocean Islands were essentially hydroxyfluorapatite, $Ca_{10}OH\ F\ (PO_4)_6$. They reported that rock phosphate from Curacao was mainly a hydrate of tricalcium phosphate, $Ca_9(H_2O)_2(PO_4)_6$. Based on this report (9), foreign sources are probably more soluble and more available than most domestic sources.

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[4] Amer, Fathi M. Characterization of soil phosphorus by exchange resin adsorption and P-32 equilibration. Unpublished Ph. D. thesis, Iowa State College, Ames, Iowa. 1954.

Table 11.--Availability of residual rock phosphate and superphosphate as measured by yields and phosphorus uptake of ladino clover grown in the greenhouse

P_2O_5 applied in-- Field (1952-56) Concentrated superphosphate	Field (1952-56) Rock phosphate	Greenhouse Concentrated superphosphate	Lloyd clay loam Gold Hill, Ala. Yield	Lloyd clay loam Gold Hill, Ala. P_2O_5 uptake	Boswell very fine sandy loam Tuskegee, Ala. Yield	Boswell very fine sandy loam Tuskegee, Ala. P_2O_5 uptake	Newtonia silt loam Fayetteville, Ark. Yield	Newtonia silt loam Fayetteville, Ark. P_2O_5 uptake	Wellston very fine sandy loam Blacksburg, Va. Yield	Wellston very fine sandy loam Blacksburg, Va. P_2O_5 uptake	Coxville fine sandy loam Summerville, S.C. Yield	Coxville fine sandy loam Summerville, S.C. P_2O_5 uptake	Chewacla silt loam Clemson, S.C. Yield	Chewacla silt loam Clemson, S.C. P_2O_5 uptake
Lb./acre	Lb./acre	Lb./acre	G.	Mg.	G.	Mg.	G.	Mg.	G.	Mg.	G.	Mg.	G.	Mg.
0	0	0	7.94	36.14	11.48	59.82	9.08	43.58	4.27	16.25	3.50	9.50	4.78	23.25
0	0	15	12.80	58.10	10.87	56.68	9.51	48.96	5.23	18.59	5.50	15.28	4.94	25.42
0	0	30	13.96	63.87	10.77	58.35	10.12	55.39	7.23	27.70	6.98	24.69	5.90	29.21
0	0	60	13.17	60.68	12.31	67.19	11.00	62.91	6.63	26.70	8.01	29.27	5.66	32.30
0	0	120	14.67	74.11	11.75	70.71	10.35	64.93	6.56	31.05	9.88	42.92	6.19	36.06
0	0	240	14.46	83.16	11.18	84.67	12.18	80.26	10.32	52.12	11.55	50.88	7.19	47.14
[1] 60	0	0	11.32	71.95	12.75	86.15	9.20	55.53	5.53	23.89	7.86	38.85	6.25	43.35
[1] 120	0	0	11.82	73.30	11.62	91.81	10.59	62.79	5.92	29.85	11.13	72.16	7.33	48.04
300	0	0	11.24	61.16	9.79	59.91	7.38	31.36	4.09	14.90	7.20	30.26	4.56	20.53
0	300	0	8.87	47.03	8.23	47.51	8.43	40.20	3.17	11.15	2.66	8.12	5.42	26.47
0	[2] 300	0	11.61	69.42	--	--	8.37	45.60	3.27	11.30	5.88	26.24	5.43	30.17
0	600	0	12.38	66.55	10.45	68.15	8.70	40.25	3.63	12.11	3.50	12.92	4.90	22.67
0	[2] 600	0	9.11	53.52	9.86	69.21	7.38	40.47	3.69	13.90	7.74	41.49	4.54	25.88
L.S.D. at 0.05....................			1.64	10.36	N.S.	14.48	1.95	9.87	1.37	7.14	1.96	10.07	1.00	5.22
L.S.D. at 0.01....................			2.23	14.10	N.S.	19.89	2.65	13.43	1.85	9.72	2.66	13.64	1.36	7.07
C.V...............................			10.7	11.7	14.1	14.1	15.3	14.8	27.9	28.7	20.6	22.1	12.6	13.0

P_2O_5 applied in-- Field (1952-56) Concentrated superphosphate	Field (1952-56) Rock phosphate	Greenhouse Concentrated superphosphate	Wickham fine sandy loam Camden, Ala. Yield	Wickham fine sandy loam Camden, Ala. P_2O_5 uptake	Plummer sandy loam Tifton, Ga. Yield	Plummer sandy loam Tifton, Ga. P_2O_5 uptake	Cecil sandy loam Watkinsville, Ga. Yield	Cecil sandy loam Watkinsville, Ga. P_2O_5 uptake	Henry silt loam Oakley, Miss. Yield	Henry silt loam Oakley, Miss. P_2O_5 uptake	Leon fine sand Gainesville, Fla. Yield	Leon fine sand Gainesville, Fla. P_2O_5 uptake
Lb./acre	Lb./acre	Lb./acre	G.	Mg.	G.	Mg.	G.	Mg.	G.	Mg.	G.	Mg.
0	0	0	6.75	30.05	1.85	4.90	28.59	151.72	12.58	44.72	10.67	25.48
0	0	15	11.60	53.80	5.64	12.69	30.97	169.49	15.24	57.83	13.78	37.40
0	0	30	12.95	61.64	8.56	22.22	31.85	165.51	17.03	66.80	16.58	50.65
0	0	60	15.39	83.64	14.27	36.04	30.47	159.19	17.84	78.09	21.34	74.90
0	0	120	14.66	88.20	18.03	56.60	33.34	214.86	21.27	108.92	24.98	121.32
0	0	240	--	--	--	--	--	--	--	--	--	--
[1] 60	0	0	18.50	90.08	15.86	60.40	29.26	182.86	15.76	79.58	15.41	49.58
[1] 120	0	0	23.37	147.69	17.73	78.57	33.18	231.86	18.03	111.73	--	--
300	0	0	17.88	85.57	6.18	19.31	31.50	186.38	--	--	--	--
0	300	0	14.71	61.73	3.10	9.23	26.97	154.51	14.83	64.56	18.70	75.80
0	[2] 300	0	--	--	--	--	--	--	--	--	--	--
0	600	0	18.03	87.01	8.74	27.89	29.38	169.27	20.88	106.41	24.61	160.92
0	[2] 600	0	14.73	94.18	--	--	--	--	--	--	--	--
L.S.D. at 0.05....................			3.25	14.53	2.03	6.78	4.87	25.46	1.90	16.40	4.98	18.58
L.S.D. at 0.01....................			4.49	20.09	2.81	9.35	6.83	37.50	2.72	22.55	7.17	28.14
C.V...............................			12.1	10.2	13.0	11.6	10.5	8.9	7.0	11.3	14.4	11.3

[1] P_2O_5 applied annually, all other treatments of P_2O_5 applied in 1952 only. [2] Unlimed, all other treatments limed

Table 12.--Extractable phosphorus and pH of soils from uniform field experiment used in residual phosphorus study in the greenhouse

Soil type and location	P_2O_5 applied (1952-56)		P_2O_5 extracted by--				pH
	Concentrated superphosphate	Rock phosphate	Dilute acid	Neutral NH_4F	HCl-NH_4F	Anion resin	
	Lb./acre	Lb./acre	P.p.m.	P.p.m.	P.p.m.	P.p.m.	
Wickham fine sandy loam, Camden, Ala........	0	0	11	30	250	10	5.5
	[1] 60	0	25	64	467	17	5.4
	[1] 120	0	60	125	621	35	5.5
	300	0	20	51	294	10	5.6
	0	300	60	37	384	11	5.8
	0	600	134	45	589	14	5.6
	0	[2] 600	192	67	749	17	5.3
Boswell very fine sandy loam, Tuskegee, Ala.	0	0	32	38	141	14	5.8
	[1] 60	0	95	137	285	43	5.9
	[1] 120	0	142	184	358	49	6.0
	300	0	62	99	256	32	5.7
	0	300	153	47	320	23	5.7
	0	600	430	66	812	34	5.7
	0	[2] 600	326	92	620	28	5.0
Lloyd clay loam, Gold Hill, Ala.............	0	0	34	65	246	23	6.1
	[1] 60	0	82	164	416	60	6.3
	[1] 120	0	140	293	621	96	6.2
	300	0	49	101	317	32	6.2
	0	300	91	69	365	22	6.3
	0	600	181	81	640	28	6.3
	0	[2] 600	209	129	789	37	6.0
Cecil sandy loam, Watkinsville, Ga..........	0	0	110	75	200	20	6.3
	[1] 60	0	120	216	424	51	6.4
	[1] 120	0	185	371	624	101	6.3
	300	0	120	240	471	62	6.4
	0	300	305	119	640	43	6.4
	0	600	421	131	640	37	6.5
Wellston very fine sandy loam, Blacksburg, Va.	0	0	20	32	103	10	6.0
	[1] 60	0	52	65	202	12	5.8
	[1] 120	0	66	114	686	27	5.8
	300	0	30	65	200	13	5.8
	0	300	44	34	197	4	5.8
	0	600	106	39	376	9	5.9
	0	[2] 600	81	47	317	12	5.0
Coxville fine sandy loam, Summerville, S.C..	0	0	10	11	73	11	6.0
	[1] 60	0	56	149	279	46	6.0
	[1] 120	0	109	232	387	66	6.0
	300	0	38	106	176	32	6.1
	0	300	97	38	293	21	6.0
	0	600	255	41	622	28	6.3
	0	[2] 600	212	117	646	37	4.8
Plummer sandy loam, Tifton, Ga..............	0	0	4	6	10	4	5.3
	[1] 60	0	25	59	70	10	5.0
	[1] 120	0	49	98	106	16	5.0
	300	0	22	19	35	4	5.3
	0	300	78	19	92	6	5.5
	0	600	92	18	134	3	5.5
Newtonia silt loam, Fayetteville, Ark.......	0	0	27	30	127	18	5.8
	[1] 60	0	57	63	169	29	5.8
	[1] 120	0	78	134	265	47	5.7
	300	0	38	41	143	17	5.6
	0	300	66	42	181	16	5.7
	0	600	118	40	286	14	5.7
	0	[2] 600	75	49	207	17	5.3
Henry silt loam, Oakley, Miss...............	0	0	18	30	203	10	4.9
	[1] 60	0	25	58	271	16	4.8
	[1] 120	0	58	134	426	34	4.8
	0	300	31	38	235	11	4.9
	0	600	65	82	388	18	4.9
Leon fine sand, Gainesville, Fla............	0	0	9	19	13	21	5.0
	[1] 60	0	24	29	34	25	5.5
	0	300	60	26	125	25	5.8
	0	600	178	30	290	50	5.5
Chewacla silt loam, Clemson, S.C............	0	0	13	67	214	21	6.0
	[1] 60	0	81	228	488	122	5.9
	[1] 120	0	136	322	657	129	5.9
	300	0	19	61	235	28	6.2
	0	300	125	75	441	34	6.1
	0	600	261	81	620	33	6.3
	0	[2] 600	185	103	563	34	5.6

[1] P_2O_5 applied annually. All other phosphate treatments applied first year only.
[2] Unlimed. All other treatments limed at beginning of field experiment.

Table 13.--Chemical and physical characterization data for sources of rock phosphate used in greenhouse studies

Source of rock phosphate	Total P_2O_5	Fluorine content	Specific surface	Fineness		Fraction of total phosphorus dissolved by various solutions				
				100 mesh	200 mesh	Sequestrene solution[1] pH 4.3	pH 5.8	pH 6.7	1 percent lactic acid	Neutral ammonium citrate
	Pct.	Pct.	M.^{2}/g.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.
Tennessee.......	34.4	3.80	7.8	100	61	17.5	18.9	8.4	6.7	4.7
Idaho...........	32.4	3.27	5.7	100	60	17.1	22.2	13.9	7.2	6.8
Florida.........	33.5	3.82	11.0	100	68	21.5	32.8	23.6	7.4	9.0
South Carolina..	26.9	3.57	6.6	100	65	35.1	44.2	42.5	8.6	17.2
Curacao Island..	38.6	.74	6.4	100	69	34.4	49.0	46.7	15.2	14.0
Morocco.........	34.1	4.27	22.4	100	84	36.3	60.9	62.9	13.4	15.7
Tunis...........	29.0	3.60	37.2	100	64	40.1	53.6	58.0	11.2	17.0

[1] Extractions were made by shaking 0.5g. of material for 2 hr. with 100 ml. of sequestrene solution made by adding 25 g. of sequestrene, ethylenedinitrilo tetraacetic acid, in 1 liter of water. The different pH values were obtained by adding 6.85 g. of NaOH for pH 4.3, 8.56 g. of NaOH for pH 5.8, and 10.28 g. of NaOH for pH 6.7.

Yields and Phosphorus Uptake from Rock Phosphate Sources

Cecil clay loam.--Yields and phosphorus uptake of three harvests of ladino clover and one harvest of sudangrass grown on Cecil clay loam are given in table 14. Curacao Island, Tunis, and South Carolina rock phosphates produced as much sudangrass and clover as an equivalent amount of P_2O_5 from superphosphate, both with and without lime. With the exception of clover without lime, Morocco rock phosphate was also as good as superphosphate. All Idaho rock phosphate was inferior to superphosphate, with the exception of clover without lime. Florida rock phosphate was inferior to superphosphate for sudangrass without lime and for clover with lime, whereas Tennessee rock phosphate was inferior only for clover with lime.

Lime increased yields of sudangrass and clover from all sources of phosphorus, but it decreased the efficiency of Idaho, Florida, and Tennessee rock phosphate relative to superphosphate as measured by clover yields. The critical need for lime on this soil is shown by the fact that lime alone increased yields and uptake of phosphorus more than phosphorus alone. This explains why lime increased yields from all sources over phosphate without lime.

Eutaw clay.--Yields and phosphorus uptake for sudangrass and ladino clover grown on Eutaw clay are presented in table 14. Superphosphate was mistakenly omitted from the unlimed pots where sudangrass was grown. However, yields of sudangrass from Idaho and Tennessee rock phosphate without lime were less than from the other sources. All raw sources produced smaller yields of clover than an equivalent amount of P_2O_5 from superphosphate both with and without lime, except Tunis rock phosphate with lime.

Phosphorus uptake by sudangrass on unlimed Idaho and Tennessee and limed Idaho, Tennessee, and Florida rock phosphate was lower than for the other raw sources. Liming reduced the efficiency of all raw phosphate relative to superphosphate as measured by phosphorus uptake by ladino clover.

Availability of Rock Phosphate as Measured by P^{32}

It is difficult to properly tag such fertilizer materials as rock phosphate. However, the "A" value technique (7) can be used to evaluate rock phosphate in the same manner that it is used to evaluate residual phosphorus effects (6). This technique was used along with yields and total phosphorus uptake to measure the effect of soil (clay mineral type), source of lime, and time of contact of rock phosphate with soil on availability.

Table 14.--Effect of rock phosphate and rates of superphosphate with and without lime on yield and phosphorus uptake of sudangrass and ladino clover grown on Cecil clay loam or Eutaw clay in the greenhouse

CECIL CLAY LOAM

Source of phosphate	P_2O_5 applied	Dry matter per pot							
		One harvest of sudangrass				Three harvests of ladino clover			
		Yield per pot		P_2O_5 Uptake per pot		Yield per pot		P_2O_5 Uptake per pot	
		Unlimed	Limed	Unlimed	Limed	Unlimed	Limed	Unlimed	Limed
	Lb./acre	G.	G.	Mg.	Mg.	G.	G.	Mg.	Mg.
None	0	1.00	2.67	2.10	9.61	6.56	9.85	21.36	31.92
Concen. superphosphate	60	1.55	3.21	6.36	14.12	7.31	12.11	27.37	40.59
Do	120	1.58	3.08	6.95	14.78	8.11	12.77	30.75	48.69
Do	240	2.23	3.85	11.82	18.87	7.86	14.89	34.70	59.71
Rock phosphate:									
Curacao Island	120	1.61	3.08	6.44	12.01	8.90	13.35	34.65	46.00
Morocco	120	1.58	3.11	6.79	12.75	7.04	13.54	30.90	46.92
Tennessee	120	1.42	2.99	5.25	10.17	8.18	11.23	30.50	36.88
Florida	120	1.19	3.00	4.76	9.90	7.76	11.22	31.62	38.27
Idaho	120	1.20	2.64	4.92	9.77	7.47	9.15	30.96	31.76
Tunis	120	1.90	2.85	9.12	11.40	9.42	12.43	36.74	43.35
South Carolina	120	1.99	3.06	8.96	11.93	8.21	13.33	31.61	43.44
L.S.D. at 0.05		0.38		3.15		0.9		6.10	
L.S.D. at 0.01		.51		4.17		1.2		8.07	

EUTAW CLAY

Source of phosphate	P_2O_5 applied	Sudangrass yield, Unlimed	Sudangrass yield, Limed	Sudangrass P_2O_5 uptake, Unlimed	Sudangrass P_2O_5 uptake, Limed	Clover yield, Unlimed	Clover yield, Limed	Clover P_2O_5 uptake, Unlimed	Clover P_2O_5 uptake, Limed
None	0	1.89	2.03	5.67	5.68	7.30	7.29	23.34	25.29
Concen. superphosphate	60	--	3.80	--	14.82	9.32	10.72	29.63	35.49
Do	120	--	4.79	--	20.60	12.34	12.81	43.24	51.27
Do	240	--	4.88	--	22.97	14.26	13.54	56.22	57.75
Rock phosphate:									
Curacao Island	120	3.63	3.70	15.97	15.54	10.45	10.29	42.11	35.39
Morocco	120	3.42	3.46	15.39	14.19	9.43	10.86	40.42	39.69
Tennessee	120	2.62	2.86	11.53	10.01	9.55	10.32	38.60	36.10
Florida	120	3.64	2.98	16.74	12.52	9.99	10.67	37.51	37.48
Idaho	120	2.65	3.21	12.19	12.20	9.72	11.37	36.37	38.99
Tunis	120	3.16	3.78	14.85	17.01	9.92	12.12	40.92	46.44
South Carolina	120	3.15	4.05	14.49	15.80	9.84	10.79	39.84	42.57
L.S.D. at 0.05		0.50		1.67		0.9		5.59	
L.S.D. at 0.01		.67		2.21		1.2		7.48	

Cecil Clay Loam

The treatments and results for the experiment involving Cecil clay loam are given in table 15. The "A" values indicate that the 640-pound rate of P_2O_5 from rock phosphate had an availability equal to only 83 pounds of P_2O_5 from superphosphate. This value was obtained by subtracting the "A" value for unphosphated soil from the "A" value of soil that had received 640 pounds of P_2O_5 from rock phosphate. The 80 pounds of P_2O_5 from superphosphate was only about 60 percent efficient. This figure is based on the difference between the "A" value of unphosphated soil and the "A" value of soil that had received 80 pounds of P_2O_5 from superphosphate. If the availability of rock phosphate is compared with the actual availability obtained for superhosphate, then 640 pounds of P_2O_5 from rock phosphate would be equivalent to about 138 pounds of P_2O_5 from freshly applied superphosphate.

Yields and total phosphorus uptake indicated a higher availability for rock phosphate than was indicated from "A" value calculations, especially for the lower rates of rock phosphate.

In the Cecil clay loam, P^{32} uptake by plants, plant yields, and total phosphorus uptake from the 160-pound rate of rock phosphate were not affected much by liming with either dolomite or calcium silicate slag but were increased by addition of silica gel.

Table 15.--Availability of rock phosphate applied to Cecil clay loam or Eutaw clay in greenhouse as measured by yields and phosphorus uptake

CECIL CLAY LOAM

Treatments[1]				First harvest, 1952			Four harvests, 1952	
Tagged superphosphate	Rock phosphate	Dolomite	Silicate slag	Yield	Phosphorus from fertilizer	Calculated "A" values	Yield	P_2O_5 uptake
Lb./acre	Lb./acre	Lb./acre	Lb./acre	G.	Pct.	Lb./acre	G.	Mg.
0	0	0	0	2.3	--	--	17.9	53.3
20	0	0	0	3.8	--	--	26.6	87.3
40	0	0	0	5.5	--	--	31.7	113.9
60	0	0	0	4.8	--	--	34.0	125.4
80	0	0	0	4.9	95.5	14	32.7	125.8
80	40	0	0	5.3	89.3	10	42.4	167.5
80	80	0	0	6.4	85.5	14	41.8	191.1
80	160	0	0	6.3	70.8	22	46.0	213.4
80	320	0	0	6.2	58.6	57	49.6	243.5
80	640	0	0	7.7	45.3	97	59.2	305.2
[2] 80	0	0	0	7.2	56.8	61	47.8	215.9
80	0	2,000	0	6.8	99.0	1	46.4	177.4
80	160	2,000	0	7.6	87.5	11	51.6	216.7
80	0	0	3,000	7.8	86.4	13	49.1	215.0
80	160	0	3,000	8.9	76.1	25	50.3	219.2
[3] 80	160	0	0	8.5	67.7	38	57.9	270.2
L.S.D. at 0.05				1.18	9.52	--	5.3	22.1
L.S.D. at 0.01				1.58	12.33	--	7.0	29.6
C.V.				12.7	8.6	--	8.6	8.4

EUTAW CLAY

Tagged superphosphate	Rock phosphate	Dolomite	Silicate slag	Yield	Phosphorus from fertilizer	Calculated "A" values	Yield	P_2O_5 uptake
0	0	0	0	3.6	--	--	10.7	41.2
20	0	0	0	4.7	--	--	13.6	57.7
40	0	0	0	5.0	--	--	14.5	69.0
60	0	0	0	5.9	--	--	14.8	76.4
80	0	0	0	5.8	98.0	2	20.3	104.5
80	40	0	0	6.2	82.9	16	18.6	103.7
80	80	0	0	7.3	69.5	35	22.5	118.4
80	160	0	0	7.6	58.0	58	28.5	145.9
80	320	0	0	7.3	47.7	88	23.5	146.9
80	640	0	0	7.1	39.1	125	32.0	198.0
[2] 80	0	0	0	8.2	52.7	72	27.0	143.9
80	0	2,000	0	5.7	102.0	--	40.5	171.6
80	160	2,000	0	6.8	77.6	23	48.2	223.1
80	0	0	3,000	6.9	92.7	6	48.1	200.0
80	160	0	3,000	8.1	87.1	12	48.9	221.0
[3] 80	160	0	0	6.5	55.4	65	33.2	178.6
L.S.D. at 0.05				1.29	8.7	--	7.96	35.2
L.S.D. at 0.01				1.73	11.7	--	10.65	47.2
C.V.				14.1	8.4	--	20.0	17.9

[1] All plots received 100 lb. of K_2O per acre.
[2] In addition to tagged superphosphate, received 80 lb. of P_2O_5 from 20 percent superphosphate.
[3] Received 2,000 lb. of silica gel per acre.

Eutaw Clay

The same treatments reported above for Cecil clay loam were applied to a Eutaw clay at the same time. The P^{32} uptake data (table 15) indicated an availability of 123 pounds of P_2O_5 for the 640-pound rate of rock phosphate. Again this was based on the difference in "A" values for phosphated and unphosphated soil. The 80 pounds of P_2O_5 from superphosphate showed an availability of 70 pounds or an efficiency of 87 percent (table 15). Based on the actual availability of freshly applied superphosphate, the 640-pound rate of rock phosphate would have an availability of about 140 pounds of P_2O_5. By this method of comparing rock phosphate with superphosphate, the

availability for the 640 pounds of P_2O_5 from rock phosphate was almost identical for the two soils.

Both dolomite and calcium silicate slag lowered the availability of rock phosphate as measured by "A" values. Based on yields and total phosphorus uptake, both liming materials increased the availability of rock phosphate. This suggests that the need for lime was more critical than the need for phosphorus.

The addition of silica gel had no effect on "A" values but did increase yields and total phosphorus uptake from rock phosphate.

Wickham Fine Sandy Loam

Based on P^{32} uptake, the 640-pound rate of P_2O_5 from rock phosphate without lime applied to Wickham fine sandy loam had an availability equal to 75 pounds of P_2O_5 from superphosphate (table 16). Lime reduced the availability of rock phosphate to zero. Yields of phosphorus by ladino clover also indicate that the 640-pound rate of rock phosphate without lime had an availability equivalent to more than 80 pounds of P_2O_5 from superphosphate. Lime reduced the availability of rock phosphate to almost zero as measured by yields of phosphorus from ladino clover.

Availability of Rock Phosphate as Affected by Time Of Contact with Soil

Claims have been made that rock phosphate becomes relatively more available with time after being mixed with the soil. Since no experiments could be found in the literature that provided a satisfactory evaluation of these claims, laboratory and greenhouse studies were initiated. Results from the greenhouse phase of the work are given in table 17. No change in availability with time of contact was indicated by the P^{32} uptake data. Yields from the second cutting of sudangrass were higher from rock phosphate applied at planting time than from rock phosphate applied 1 year before planting. Yields for the first cutting decreased in magnitude with increased time of contact. The availability of rock phosphate as compared with superphosphate was very low regardless of the time of contact.

Availability of Rock Phosphate as Affected by Source And Time of Application of Lime

A greenhouse experiment was conducted to determine the effect of two sources and time of application of lime on availability of rock phosphate. Ladino clover was used as the test crop. Dolomitic limestone and blast furnace slag were the two sources of lime used. Each source was applied 3 months before planting and at planting.

Vaiden clay

Yield data for the Vaiden clay are presented in table 18 and figure 4. There was a yield response to dolomite alone applied 3 months before planting and to silicate slag alone applied at planting time. Calcium silicate slag produced higher yields with both kinds of phosphate than did dolomite at the same rates, but this differential effect was far more pronounced with rock phosphate than with superphosphate. Yields from rock phosphate with calcium silicate slag applied 3 months before planting were as good as or better than those from superphosphate with dolomite applied 3 months before planting. Dolomite lowered yields from rock phosphate regardless of the time of application. In general the earlier application of both liming materials to rock

Table 16.--Availability of Florida rock phosphate applied to a Wickham fine sandy loam as measured by P^{32} uptake and yields of phosphorus by ladino clover grown in the greenhouse

P_2O_5 applied		Ladino clover			
		Total uptake of P_2O_5		"A" values	
Super-phosphate	Rock phosphate	Unlimed	Limed [2]	Unlimed	Limed[2]
Lb./acre	Lb./acre	Mg.	Mg.	Lb./acre	Lb./acre
0	0	29.2	34.6	--	--
40	0	30.7	37.4	--	--
[1] 80	0	36.2	40.4	194	182
[1] 120	0	37.0	44.3	--	--
240	0	38.4	48.4	233	172
0	80	32.6	33.6	--	--
0	160	32.7	31.5	--	--
0	320	36.8	34.7	--	--
0	640	39.0	36.7	--	--
[1] 80	80	37.4	39.3	197	177
[1] 80	160	38.6	41.4	202	177
[1] 80	320	43.7	39.9	264	172
[1] 80	640	40.3	40.2	269	171
L.S.D. at 0.05		4.4	4.4	--	--
L.S.D. at 0.01		5.8	5.8	--	--
C.V.		9.3.	9.3	--	--

[1] Tagged superphosphate.
[2] Limed at rate of 2,000 lb. of dolomite per 2 million lb. of soil.

Table 17.--Effect of time of contact with moist soil[1] on availability of rock phosphate as measured by P^{32} uptake and yields of sudangrass

Treat-ment No.	Length of time phosphate in contact with soil	P_2O_5 applied		Yield per pot	P_2O_5 in plants		Second cutting		Sum of two cuttings per plot
		Tagged superphos-phate	Rock phosphate		From fertilizer	Total	Yield per pot	Total P_2O_5 in plants	
		Lb./acre	Lb./acre	G.	Pct.	Pct.	G	Pct.	G.
1....	Applied at planting......	0	0	3.91	--	0.30	4.21	0.29	8.12
2....	......do.................	50	0	7.68	89.4	.29	8.12	.35	15.80
3....	......do.................	100	0	8.64	--	.26	9.31	.37	17.95
4....	......do.................	200	0	10.54	--	.28	9.48	.38	19.99
5....	1 year before planting...	0	200	4.56	--	.26	4.92	.40	9.48
6....	......do.................	50	200	7.70	81.3	.28	8.33	.38	16.03
7....	6 months before planting.	0	200	4.91	--	.26	6.10	.36	11.01
8....	......do.................	50	200	7.31	80.0	.30	8.45	.40	15.76
9....	Applied at time of planting...............	0	200	5.33	--	.28	6.50	.38	11.83
10....	......do.................	50	200	7.33	78.4	.31	8.48	.38	15.81
	L.S.D. at 0.05...........	--	--	0.9	--	--	1.4	--	--
	L.S.D. at 0.01...........	--	--	1.2	--	--	1.8	--	--

[1] Wickham fine sandy loam with pH 5.2.

Table 18.--The effect of rate, kind, and time of application of lime on availability of rock phosphate and superphosphate as measured by yields and phosphorus uptake of three harvests of ladino clover

Treatments				Vaiden clay				Lloyd clay loam			
Source of lime		P_2O_5 applied		Lime applied 3 mo. before planting		Lime applied at planting time		Lime applied 3 mo. before planting		Lime applied at planting time	
Dolomite	Calcium silicate slag	Super-phosphate	Rock phosphate	Yield	P_2O_5 uptake	Yield	P_2O_5 uptake	Yield	P_2O_5 uptake	Yield	P_2O_5 uptake
Lb./acre	Lb. acre	Lb./acre	Lb./acre	G.	Mg.	G.	Mg.	G.	Mg.	G.	Mg.
0	0	80	0	9.00	36.28	9.00	36.28	11.01	38.73	11.01	38.73
1,000	0	80	0	9.13	37.18	10.70	44.23	14.10	47.75	11.82	40.74
2,000	0	80	0	11.02	45.98	10.62	41.97	14.26	48.99	13.89	50.32
4,000	0	80	0	11.64	45.81	11.16	44.91	14.94	55.42	14.76	51.93
0	1,000	80	0	13.57	64.42	14.26	67.46	12.21	46.87	12.90	45.53
0	2,000	80	0	14.45	69.59	15.61	76.87	13.49	49.30	15.05	52.26
0	4,000	80	0	15.73	76.84	16.35	80.89	13.69	52.49	16.42	57.96
0	0	0	80	8.45	33.12	8.45	33.12	8.62	27.56	8.62	27.56
1,000	0	0	80	7.89	30.18	6.81	27.72	6.35	18.81	5.57	15.67
2,000	0	0	80	6.20	21.05	5.16	16.41	4.53	13.26	4.69	13.61
4,000	0	0	80	4.71	16.13	3.69	11.09	7.17	21.84	6.93	20.57
0	1,000	0	80	13.02	56.91	7.70	30.30	7.54	23.39	8.84	26.75
0	2,000	0	80	13.67	64.10	7.26	27.47	7.33	21.88	7.44	23.37
0	4,000	0	80	13.27	57.05	5.94	20.60	5.90	17.23	6.79	20.42
0	0	0	0	2.39	6.40	2.39	6.40	3.72	9.89	3.72	9.81
1,000	0	0	0	2.76	7.39	2.80	7.32	3.69	9.59	3.21	8.61
2,000	0	0	0	3.72	10.31	2.83	7.57	4.03	10.30	4.25	12.25
4,000	0	0	0	5.13	14.84	2.57	6.90	6.33	19.53	5.77	16.65
0	1,000	0	0	4.35	12.59	7.96	27.15	3.48	9.01	3.92	10.07
0	2,000	0	0	3.79	11.15	8.49	27.20	3.95	10.44	4.03	11.06
0	4,000	0	0	3.94	13.38	9.57	33.26	5.00	13.71	5.20	14.63
4,000	0	40	0	9.06	28.26	8.70	28.18	12.18	40.30	11.91	38.98
4,000	0	120	0	14.82	67.41	13.45	66.34	15.34	65.54	16.46	69.88

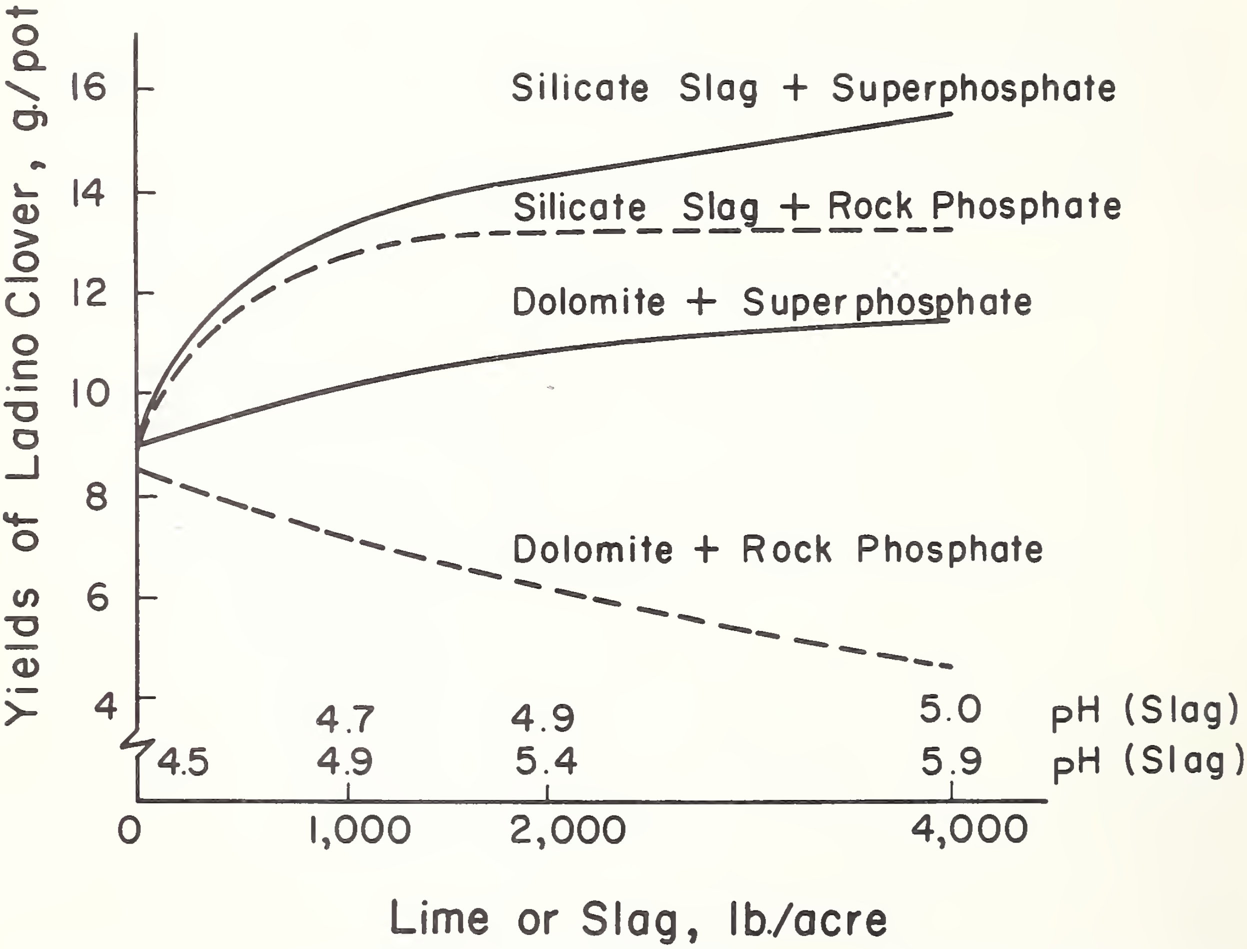

Figure 4.--Effect of dolomite and calcium silicate slag applied 3 months before planting on availability of superphosphate and rock phosphate as measured by yields of ladino clover grown in the greenhouse on Vaiden clay.

phosphate resulted in higher yields than did application at planting time. With superphosphate the time of lime application had no effect on yields.

In general the phosphorus uptake data confirmed the yield data (table 18). In fact, differences due to sources and time of lime application were even more striking for phosphorus uptake than for yields. There was a definite increase in phosphorus uptake with increasing rates of dolomite with or without superphosphate and a very sharp decrease with rock phosphate, regardless of time of application of lime. The 1,000-pound application of calcium silicate slag was about as effective as the 4,000-pound rate. Also, there was no lowering of phosphorus uptake from rock phosphate when slag was applied 3 months before planting.

Slag alone applied at planting time increased yields and phosphorus uptake much more than did dolomite alone. This suggests that the slag rendered the soil phosphorus more available. The fact that dolomite decreased yields and phosphorus uptake from rock phosphate and that the slag did not can be explained, at least in part, by the pH values obtained for the two liming materials (table 19). The slag evidently furnished enough calcium for the clover without raising the pH of this soil enough to interfere with the availability of rock phosphate.

Lloyd clay loam

The effects of source and time of application of lime on rock phosphate availability for the Lloyd clay loam (table 18 and fig. 5) were quite different from those obtained for the Vaiden clay reported above.

In contrast to the Vaiden soil, rock phosphate was an ineffective source of phosphorus for the Lloyd clay loam when used with either source of lime regardless of time of application. Without lime the relative efficiency of rock phosphate (increased yields from superphosphate = 100 percent) was 92 percent for the Vaiden and 67 for the Lloyd. The lower pH of the Vaiden undoubtedly favored the availability of rock phosphate.

Comparative responses of the two soils to superphosphate and rock phosphate suggest that it is not possible to lime a soil such as Lloyd clay loam sufficiently for production of ladino clover without raising the pH enough to lower the availability of rock phosphate.

Table 19.--The effect of kind, rate, and time of application of lime, and of added soluble aluminum, on the pH reaction of Vaiden clay and Lloyd clay loam

Kind and rate of lime applied			Reaction 3 months after applying lime		Reaction 7 months after applying lime		Reaction 10 months after applying lime	
Dolomite	Calcium silicate slag	Soluble aluminum	Vaiden	Lloyd	Vaiden	Lloyd	Vaiden	Lloyd
Lb/acre	Lb/acre	P.p.m.,	pH	pH	pH	pH	pH	pH
0	0	0	4.5	5.2	4.5	5.4	4.5	5.5
1,000	0	0	4.9	5.8	4.8	6.0	4.7	5.7
2,000	0	0	5.4	6.2	5.1	6.4	5.0	6.2
4,000	0	0	5.9	6.8	5.6	6.9	5.5	6.8
0	1,000	0	4.7	5.3	4.7	5.6	4.7	5.6
0	2,000	0	4.9	5.6	4.9	5.7	4.9	5.9
0	4,000	0	5.0	5.9	5.1	6.2	5.0	6.3
0	0	200	--	--	4.3	--	4.3	--
1,000	0	200	--	--	4.3	--	4.5	--
2,000	0	200	--	--	4.5	--	4.6	--
4,000	0	200	--	--	5.0	--	5.0	--
0	0	50	--	--	--	4.9	--	4.9
1,000	0	50	--	--	--	5.6	--	5.6
2,000	0	50	--	--	--	6.1	--	6.1
4,000	0	50	--	--	--	6.6	--	6.6

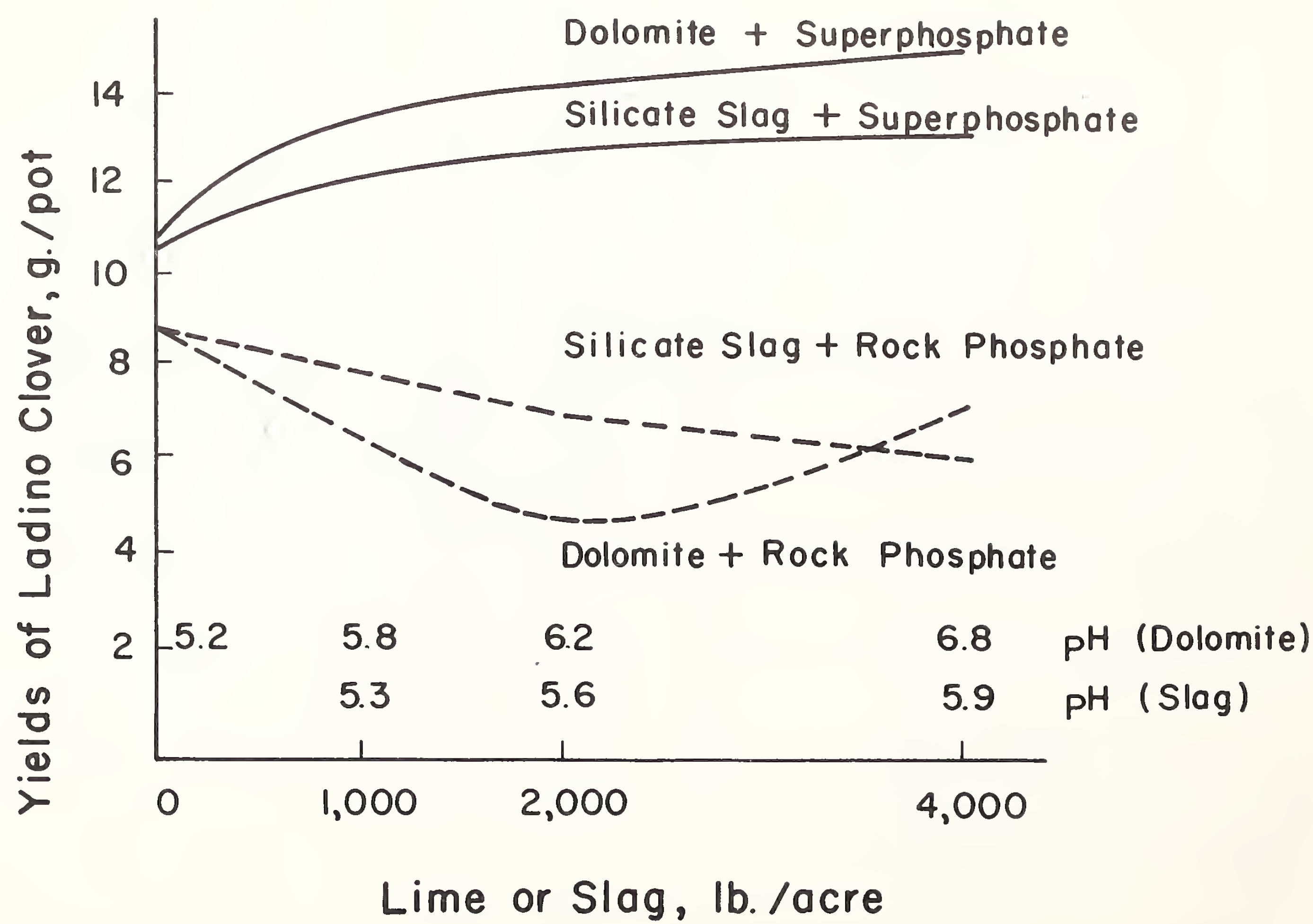

Figure 5.--Effect of dolomite and calcium silicate slag applied 3 months before planting on availability of superphosphate and rock phosphate as measured by yields of ladino clover grown in greenhouse on Lloyd clay loam.

CONCLUSIONS

Field Experiments

1. The effectiveness of rock phosphate varied widely among soils of the region but was seldom more than one-fourth that of superphosphate applied at the same rate of phosphorus.

2. Differences in effectiveness of rock phosphate could not be explained on the basis of commonly measured soil characteristics.

3. The residual effect of rock phosphate was less or no better than that of superphosphate applied at one-half the rate of phosphorus.

4. The different soils fall in the same order when ranked on the basis of immediate or residual effectiveness of rock phosphate.

5. Extrapolation of yield curves indicated that maximum yield could not be reached at any rate of phosphorus with rock phosphate as the source.

6. There was no significant effect of lime on the relative effectiveness of rock phosphate.

Greenhouse and Laboratory Experiments

1. About 6 pounds of P_2O_5 from rock phosphate were required to produce the same yields as 1 pound from superphosphate.

2. Rock phosphate alone did not produce maximum yields even when applied at high rates.

3. The residual effect of 300 pounds of P_2O_5 from superphosphate initially was less than 60 pounds annually. In general, the residual effect of rock phosphate was less than equivalent amounts of P_2O_5 from superphosphate. For most soils, extractable phosphorus was higher where 60 pounds of P_2O_5 from superphosphate were applied annually as compared with 300 pounds applied initially.

4. The foreign sources of rock phosphate tested were superior to all the domestic sources tested except that from South Carolina. Solubility in sequestrene and citrate solutions was a better measure of availability of rock phosphates than fluorine content or specific surface.

5. The use of tagged superphosphate indicated that 640 pounds of P_2O_5 from rock phosphate applied to either unlimed Cecil clay loam or Eutaw clay had an availability equivalent to about 140 pounds of P_2O_5 from superphosphate. Liming Cecil clay loam with dolomite lowered P^{32} uptake slightly but increased yield. Silicate slag did not affect P^{32} uptake but increased yield. Liming Eutaw clay with either dolomite or silicate slag increased P^{32} uptake, yield, and total phosphorus uptake. Liming Wickham fine sandy loam reduced the availability of rock phosphate almost to zero as measured by P^{32} uptake, yields, and total phosphorus uptake by ladino clover.

6. Rock phosphate applied to a Wickham fine sandy loam did not change in availability with time of contract with soil as measured by P^{32} uptake and yields of first cutting of sudangrass. Yields for the second cutting showed that rock phosphate applied at planting time was more available than that applied 1 year before planting.

7. The time of application of dolomite or silicate slag with superphosphate had no effect on yields or phosphorus uptake of ladino clover grown on Vaiden clay or Lloyd clay loam. However, yields and phosphorus uptake were increased by both sources of lime. Dolomite applied with rock phosphate reduced yields and phosphorus uptake regardless of time of application. Yields and phosphorus uptake from rock phosphate with calcium silicate slag were as high as or higher than from superphosphate with dolomite for ladino clover grown on Vaiden clay. However, calcium silicate slag reduced yields and phosphorus uptake of ladino grown on Lloyd clay loam.

8. For Vaiden soil, the higher efficiency of rock phosphate and calcium silicate slag as compared with rock phosphate and dolomite can be explained, at least in part, by the lower pH values resulting from the slag treatments. The slag evidently furnished enough calcium for the clover without raising the pH of the Vaiden clay enough to interfere with the availability of rock phosphate. Rock phosphate was somewhat more efficient with silicate slag than with dolomite for the Lloyd clay loam. Both slag and dolomite increased the pH of Lloyd clay loam more than that of Vaiden clay.

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APPENDIX TABLE 20.--Dry matter yield response of ladino clover to phosphorus applied as rock phosphate and concentrated superphosphate to Wickham fine sandy loam, Camden, Ala.

Treatment			Treatment period and clipping yield									Average yields 1953-57	
			1953		1954			1955			1957		
Super-phosphate	Rock phosphate	Lime	First	Second	First	Second	Third	First	Second	Third	First	First	Total
Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre
[1] 180	0	2,000	2,822a	1,685ab	2,279a	2,130a	1,583ab	974a	1,665a	1,025ab	1,083a	1,789a	3,811a
[1] 120	0	2,000	2,788a	1,712ab	2,146a	2,001a	1,685a	854abc	1,597ab	1,063ab	1,070a	1,714ab	3,729ab
[1] 60	0	2,000	2,736a	1,626abc	2,164a	1,902a	1,551ab	932ab	1,557ab	1,132a	1,055a	1,722ab	3,664ab
[1] 30	0	2,000	2,610a	1,477 bcd	2,062a	2,041a	1,247 c	665 bcd	1,254 bc	858abc	742a	1,519 bc	3,239 cd
[2] 300	0	2,000	2,680a	1,909a	1,829abc	2,024a	1,558ab	662 bcd	1,364abc	1,000ab	670a	1,460 bc	3,392 bc
[2] 150	[2] 300	2,000	2,812a	1,588 bc	1,886ab	1,899a	1,461abc	547 d	1,309abc	805 bcd	734a	1,495 bc	3,291 cd
[2] 75	[2] 300	2,000	2,644a	1,463 bcd	1,805abc	2,001a	1,438abc	598 cd	1,329abc	974ab	839a	1,471 bc	3,272 cd
[1] 60	0	0	2,155 bc	1,257 d	1,278 bcd	2,071a	1,298 bc	402 d	1,333abc	683 cd	1,234a	1,267 c	2,927 d
0	[2] 600	2,000	2,576a	1,599 bc	1,752abc	2,056a	1,339 bc	466 d	1,322abc	824 bcd	952a	1,436 c	3,221 cd
0	[2] 600	0	2,567a	1,531 bcd	1,176 cd	2,114a	1,479abc	468 d	826 d	679 cd	1,037a	1,312 c	3,291 cd
0	[2] 300	2,000	2,447ab	1,343 cd	1,339 bcd	1,978a	1,352 bc	389 d	1,367abc	773 bcd	975a	1,287 c	2,991 d
0	0	2,000	2,017 c	1,230 d	887 d	1,979a	945 d	404 d	1,053 cd	564 d	691a	999 d	2,442 c

[1] Applied annually.
[2] Applied first year only.
[3] Duncan's Multiple Range Test, p = 0.05. Values followed by the same letter do not differ significantly.

APPENDIX TABLE 21.--Residual effect of phosphorus application on dry matter yield of ladino clover grown on Wickham fine sandy loam, Camden, Ala.

Treatment			Residual phase and clipping yield				Average yields 1958-59	
			1958		1959			
Super-phosphate	Rock phosphate	Lime	First	Second	First	Second	First	Total
Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre
[1] 180	0	2,000	3,467a	1,767a	2,144ab	1,592ab	2,805a	4,485a
[1] 120	0	2,000	2,861abc	1,927a	1,746 b	1,629ab	2,303ab	4,081ab
[1] 60	0	2,000	3,358a	1,365abc	1,619 bc	1,301 bcd	2,488ab	3,822ab
[1] 30	0	2,000	2,765abc	1,463ab	2,256a	1,649ab	2,510ab	4,066ab
[2] 300	0	2,000	2,721abc	1,607ab	1,837 b	1,337abcd	2,279ab	3,751ab
[2] 150	[2] 300	2,000	2,642abc	1,576ab	1,646 b	1,676a	2,144 bc	3,770ab
[2] 75	[2] 300	2,000	2,966ab	1,086 bc	1,731 b	1,472abc	2,348ab	3,627ab
[1] 60	0	0	1,946 bc	789 c	1,542 bc	1,163 cd	1,724 bc	2,720 b
0	[2] 600	2,000	2,834abc	1,466ab	1,832 b	1,877abcd	2,33ab	4,004ab
0	[2] 600	0	2,713abc	1,065 bc	1,322 c	1,381abcd	2,017 cd	3,240 c
0	[2] 300	2,000	2,405abc	1,390abc	1,662 b	1,286 bcd	2,033 bc	3,371 b
0	0	2,000	1,698 c	1,145 bc	1,020 d	1,066 d	1,359 d	2,464 c

[1] Applied annually.
[2] Applied first year only.

APPENDIX TABLE 22.--Residual effect of phosphorus application on dry matter on yield of ladino clover grown on Boswell very fine sandy loam, Tuskegee, Ala.

Treatment			Treatment period and clipping yield					Average yields 1953-57		Residual phase 1958
			1953		1954	1957				
Super-phosphate	Rock phosphate	Lime	First	Second	First	First	Second	First	Total	First clipping
Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre
[1] 180	0	2,000	1,972a	746ab	1,491a	3,535a	958a	2,333a	1,937 bc	2,901a
[1] 120	0	2,000	1,709ab	708ab	926 b	3,358a	927a	1,998ab	2,970ab	2,543abc
[1] 60	0	2,000	1,605ab	631ab	1,422ab	2,943a	714a	1,990ab	2,188abc	2,444 cd
[1] 30	0	2,000	1,239 b	688ab	1,207ab	3,165a	939a	1,870ab	2,131abc	2,413abcd
[2] 300	0	2,000	2,000a	582 b	1,447a	2,913a	799a	2,120ab	2,775ab	2,580abcd
[2] 150	[2] 300	2,000	1,605ab	701ab	1,226ab	3,670a	1,131a	2,167ab	2,035abc	2,777ab
[2] 75	[2] 300	2,000	1,580ab	706ab	1,289ab	2,915a	1,014a	1,928ab	2,215abc	2,501abcd
[1] 60	0	0	1,324 b	669ab	1,387ab	3,895a	715a	2,202ab	1,140 c	2,663abc
0	[2] 600	2,000	1,327 b	703ab	1,081ab	3,073a	974a	1,827ab	2,661ab	2,386 cd
0	[2] 600	0	2,130a	801a	1,306ab	3,258a	743a	2,231a	2,510ab	2,746abc
0	[2] 300	2,000	1,280 b	693ab	1,216ab	2,747a	944a	1,747ab	3,325a	2,293 bcd
0	0	2,000	1,118 b	616 b	1,102ab	2,964a	851a	1,728 b	2,120abc	2,217 d

[1] Applied annually.
[2] Applied first year only.

APPENDIX TABLE 23.--Dry matter yield response of ladino clover to phosphorus applied as rock phosphate and concentrated superphosphate to Newtonia silt loam, Fayetteville, Ark.

Treatment			Treatment period and clipping yield						Average yields 1956-57	
			1956		1957					
Super-phosphate	Rock phosphate	Lime	First	Second	First	Second	Third	Fourth	First	Total
Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre
[1] 120	0	2,000	2,155ab	1,112abc	2,506a	1,467ab	641ab	1,087ab	2,380ab	4,484abc
[1] 60	[2] 300	2,000	2,143ab	1,174abc	2,314abc	1,405abcd	559 b	1,022ab	2,228abc	4,308abcd
[1] 60	[2] 300	1,000	2,528ab	1,013abc	2,064abc	1,065 bcd	532 b	693 b	2,296abc	3,947abcd
[1] 60	0	2,000	2,530ab	1,388ab	2,270abc	1,668a	1,033a	1,136a	2,400a	5,012ab
[1] 30	[2] 600	2,000	2,550ab	1,448a	2,097abc	1,460abc	879ab	1,083ab	2,323ab	4,758ab
[1] 30	[2] 300	2,000	2,393ab	1,057abc	1,634 c	1,668a	853ab	1,024ab	2,013abc	4,314abcd
[1] 30	0	2,000	2,740a	990abc	1,966abc	1,338abcd	588ab	878ab	2,353ab	4,250abcd
[1] 15	0	2,000	1,912ab	923 bc	1,999abc	1,171 bcd	654ab	875ab	1,955abc	3,767 bcd
[2] 300	0	2,000	2,470ab	1,173abc	2,384ab	1,409abcd	688ab	935ab	2,427a	4,529abc
0	[2] 600	2,000	2,245ab	1,078abc	1,998abc	1,350abcd	717ab	980ab	2,121abc	4,184abcd
0	[2] 600	1,000	2,345ab	1,223abc	2,213abc	1,348abcd	768ab	1,020ab	2,279abc	4,458abcd
0	[2] 600	0	2,130ab	1,290abc	1,805 bc	1,331abcd	757ab	1,105a	1,967abc	4,209abcd
0	[2] 300	2,000	2,268ab	1,125abc	1,933abc	1,371abcd	760ab	957ab	2,100abc	4,207abcd
0	[2] 300	1,000	2,113ab	1,100abc	1,789 bc	1,358abcd	595ab	913ab	1,951abc	3,934abcd
0	[2] 300	0	1,847ab	1,083abc	1,618 c	989 d	523 b	1,125a	1,732 bc	3,592 bcd
0	0	2,000	2,003ab	1,113abc	2,308abc	1,360abcd	862ab	978ab	2,155abc	4,312abcd
0	0	1,000	1,583 b	838 c	2,151abc	1,022 bcd	479 b	761ab	1,867abc	3,417 cd
0	0	0	1,728 b	860 c	1,636 c	1,004 cd	572ab	768ab	1,682 c	3,284 d

[1] Applied annually. [2] Applied first year only.

APPENDIX TABLE 24.--Residual effect of phosphorus application on dry matter yield of ladino clover grown on Newtonia silt loam, Fayetteville, Ark.

Treatment			Residual phase and clipping yield						Average yields 1959-60	
			1959			1960				
Super-phosphate	Rock phosphate	Lime	First	Second	Third	First	Second	Third	First	Total
Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre
[1] 120	0	2,000	2,748abc	1,615abcd	1,430a	3,559ab	1,898a	1,710a	3,153ab	6,480ab
[1] 60	[2] 300	2,000	2,752abc	1,474abcde	1,191abc	3,401abc	1,582abc	1,492abcd	3,077ab	5,946abc
[1] 60	[2] 300	1,000	2,201 def	1,198 defg	1,098abcde	2,730 defg	1,521abc	1,396abcde	2,466 de	5,072 defg
[1] 60	0	2,000	2,656abcd	1,701abc	1,274abc	3,399abc	1,927a	1,592abcd	3,028abc	6,275abc
[1] 30	[2] 600	2,000	2,893ab	1,871a	1,281ab	3,510ab	1,854a	1,693ab	3,202ab	6,552ab
[1] 30	[2] 300	2,000	2,381 bcde	1,783ab	1,178abcd	3,428abc	1,866a	1,378 bcde	2,905 bcd	6,007abcd
[1] 30	0	2,000	3,017a	1,764ab	1,256abc	3,871a	1,868a	1,706a	3,444a	6,741a
[1] 15	0	2,000	1,955 efg	1,113 efgh	938 bcdef	2,140 gh	1,329 bcd	1,338 cde	2,047 fgh	4,406 fgh
[2] 300	0	2,000	2,267 cdef	1,507abcde	1,066 bcde	2,873 cde	1,618abc	1,546abcd	2,570 cde	5,438 cde
0	[2] 600	2,000	2,187 def	1,356 bcdef	1,091abcde	3,039 bcd	1,688ab	1,584abcd	2,613 cde	5,472 cde
0	[2] 600	1,000	2,554abcd	1,485abcde	1,245abc	3,026 bcd	1,621abc	1,441abcd	2,790 bcd	5,685 bcd
0	[2] 600	0	2,134 def	1,158 defgh	1,067 bcde	2,823 cdef	1,741ab	1,706a	2,478 def	5,314 cdef
0	[2] 300	2,000	2,214 def	1,349 bcdef	1,084abcde	2,946 bcd	1,688ab	1,574abcd	2,580 cde	5,427 cde
0	[2] 300	1,000	1,830 fg	1,089 efgh	916 cdef	2,597 defg	1,462abc	1,318 de	2,213 efg	4,607 efgh
0	[2] 300	0	1,853 efg	818 gh	828 def	2,281 efgh	1,356 bcd	1,492abcd	2,067 fgh	4,314 gh
0	0	2,000	1,617 g	1,263 cdef	1,016 bcdef	2,238 fgh	1,588abc	1,648abc	1,928 gh	4,685 efgh
0	0	1,000	1,487 gh	935 fgh	752 ef	1,912 h	1,169 cd	1,307 de	1,699 hi	3,780 hi
0	0	0	1,118 h	732 h	677 f	1,721 h	1,023 d	1,124 e	1,419 i	3,197 i

[1] Applied annually.
[2] Applied first year only.

APPENDIX TABLE 25.--Yield response of ladino clover to phosphorus applied as rock phosphate and concentrated superphosphate to Leon fine sand, Gainesville, Fla.

Treatment			Treatment period and clipping yield										Residual phase	
Super- phosphate	Rock phosphate	Lime	1953		1954		1955		1956		1957		1958	
			First	Third	First	Third	First	Fourth	First	Fourth	First	Fourth	First	Total
Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre
60	0	2,000	1,632a	1,479a	3,084a	2,820ab	2,341a	1,797a	679abc	2,614a	3,098ab	492ab	543 c	7,161 c
[1] 30	[2] 300	2,000	1,468ab	1,648a	2,940a	2,875a	2,285ab	1,791a	750ab	2,589ab	3,142a	545a	977 b	8,766ab
[3] 30	0	2,000	1,189 b	1,740a	2,925a	2,472 cd	1,908abc	1,632a	355 de	2,348 bc	2,583 bc	449 bc	923 b	8,391 b
[1] 15	[2] 300	2,000	1,192 b	1,533a	3,154a	2,581 bc	2,154abc	1,717a	599 bcd	2,415abc	2,916ab	475ab	1,056 b	8,620ab
[3] 15	0	2,000	495 c	1,467a	2,519 b	2,591 bc	1,732 c	1,613a	215 e	2,018 c	2,126 c	429 bc	135	5,396 d
0	[2] 600	2,000	476 c	1,614a	3,080a	2,314 d	1,901abc	1,721a	897a	2,946a	3,230a	447 bc	1,498a	9,569a
0	[2] 300	2,000	436 c	1,574a	2,861a	2,438 cd	1,862 bc	1,642a	459 cde	2,329 c	2,771ab	391 c	986 b	8,245 b

[1] Applied annually
[2] Applied first year only.
[3] Applied annually; double rate first year.

APPENDIX TABLE 26.--Yield response of ladino clover to phosphorus applied as rock phosphate and concentrated superphosphate to Coxville fine sandy loam, Clemson, S.C.

Treatment			Treatment period[1]		Residual phase			Average yields 1956-60	
			1956	1958	1959		1960		
Super-phosphate	Rock phosphate	Lime	First clipping	First clipping	First clipping	Second clipping	First clipping	First	Total
Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre
[2] 120	0	2,030	1,909abcd	2,621ab	2,582a	942ab	898ab	1,740ab	2,210ab
[2] 60	0	2,030	1,665 bcde	1,382 d	2,388a	809 bc	662 bcdef	1,525ab	1,930ab
[2] 30	0	2,030	1,563 cdef	1,785 bcd	1,857abc	725 bcde	559 bcdefg	1,208 bcde	1,571 bcde
[2] 15	0	2,030	1,813 bcd	2,096abcd	1,114 cd	535 cdef	323 efg	719 e	986 ef
[3] 600	0	2,030	2,207ab	2,563abc	2,538a	1,182a	1,182a	1,860a	2,450a
[3] 300	0	2,030	2,430a	2,707a	2,025ab	647 bcdef	732 bcde	1,379abcd	1,702 bcd
0	[3] 600	2,030	2,053abc	2,259abc	2,334a	745 bcd	599 bcdefg	1,466abc	1,839abc
0	[3] 600	1,128	1,489 cdef	2,087abcd	2,326a	810 bc	772 bcd	1,549ab	1,954ab
0	[3] 600	0	1,159 ef	2,022abcd	2,042ab	799 bc	819abc	1,430abcd	1,830abc
0	[3] 300	2,030	1,619 bcdef	1,872abcd	1,938ab	671 bcde	512 bcdefg	1,225 bcde	1,560 bcde
0	[3] 300	1,128	1,441 cdef	2,122abcd	1,471 bcd	427 ef	378 defg	924 def	1,138 def
0	[3] 300	0	1,149 ef	2,156abc	1,449 bcd	497 cdef	441 cdefg	945 cdef	1,193 cdef
0	0	2,030	1,782 bcd	1,958abcd	1,013 d	483 def	244 fg	628 f	870 f
0	0	1,128	1,287 def	1,709 cd	865 d	268 f	150 g	507 f	641 f
0	0	0	1,042 f	2,019abcd	1,058 cd	284 f	252 fg	655 f	798 f

[1] Alfalfa in 1956, ladino clover in all subsequent years.
[2] Annually.
[3] Applied first year only.

APPENDIX TABLE 27.--Residual effect of phosphorus application on yield of ladino clover grown on Coxville fine sandy loam, Summerville, S.C.

Treatment			Treatment period and clipping yield						
Super-phosphate	Rock phosphate	Lime	1955	1956		1957	1958	Average 1955-58	Residual phase 1959
			First	First	Second	First	First	First	First
Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre
[1] 120	0	7,400	1,413 b	1,067ab	919a	1,737ab	691abc	1,227ab	585a
[1] 60	0	7,400	928 c	999ab	838ab	1,798a	621abcd	1,086 bc	578a
[1] 30	0	7,400	818 c	759 bc	907a	1,792a	678abc	1,012 c	519a
[1] 15	0	7,400	753 c	696 bc	781ab	1,543ab	493 bcde	871 cd	104 b
[2] 300	0	7,400	1,908a	1,104ab	605abcd	1,332 b	829ab	1,293ab	252 b
[2] 600	0	7,400	1,733ab	1,402a	658abc	1,679ab	912a	1,431a	--
0	[2] 600	7,400	809 c	685 bc	715abc	927 c	358 cdef	695 de	763a
0	[2] 600	3,350	949 c	753 bc	744ab	1,463ab	454 cdef	905 cd	200 b
0	[2] 600	0	919 c	858 bc	646abc	822 cd	278 def	719 de	193 b
0	[2] 300	7,400	871 c	696 bc	642abc	597 cde	342 cdef	626 ef	--
0	[2] 300	3,350	801 c	873 b	793ab	843 cd	352 cdef	717 de	--
0	[2] 300	0	844 c	324 cd	417 cd	453 de	125 f	436 fg	--
0	0	7,400	766 c	581 bcd	535 bcd	461 de	240 ef	512 efg	--
0	0	3,350	770 c	664 bc	757ab	480 de	256 ef	543 ef	--
0	0	0	740 c	152 d	327 d	206 e	103 f	300 g	--

[1] Applied annually.
[2] Applied first year only.

APPENDIX TABLE 28.--Yield response of ladino clover to phosphorus applied as rock phosphate and concentrated superphosphate to Wellston very fine sandy loam, Blacksburg, Va.

Treatment			Treatment period and clipping yield									Average yields 1953-58	
Super-phosphate	Rock phosphate	Lime	1953	1954		1955	1956	1957		1958			
			First	First	Second	First	First	First	Second	First	Second	First	Total
Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre
[1] 120	0	4,000	1,485a	1,605a	954a	1,583a	2,802ab	1,056ab	1,032abcd	1,907abc	1,354ab	1,739a	2,296
[1] 60	0	4,000	909ab	1,097 bc	997a	1,392ab	2,919a	858abcde	1,212ab	2,266a	1,394ab	1,557ab	2,158
[1] 30	0	4,000	973 b	1,241ab	815 bc	1,376abc	2,524abc	1,092a	1,190ab	2,113ab	1,446a	1,553ab	2,128
[1] 15	0	4,000	907ab	1,289ab	768 cd	1,248abcd	2,816a	1,098a	1,297a	2,057ab	1,197abcd	1,569ab	2,113
[2] 300	0	4,000	742 b	1,219ab	812 bc	1,018 bcd	2,820a	996abc	1,160abc	1,964abc	1,277abc	1,460abc	2,001
0	[2] 600	4,000	798 b	995 bc	790 bc	984 bcd	2,402abc	965abcd	952abcde	1,597abcde	1,175 bcd	1,290 bcde	1,776
0	[2] 600	2,000	684 b	950 bc	724 cde	1,038abcd	2,596abc	693 cdef	759 defg	1,316 cde	992 cde	1,213 bcde	1,625
0	[2] 600	0	811 b	936 bc	764 cd	973 bcd	2,122abcd	728 bcdef	670 efg	1,191 de	1,032 cde	1,127 cdef	1,538
0	[2] 300	4,000	603 b	975 bc	711 cde	1,265abcd	2,554abc	984abc	930 bcde	1,947abc	1,360ab	1,388abcd	1,881
0	[2] 300	2,000	742 b	869 bc	678 cde	941 bcd	2,013 bcd	686 cdef	992abcde	1,552 bcde	1,154 bcd	1,129 cdef	1,599
0	[2] 300	0	644 b	904 bc	726 cde	717 d	1,914 cd	576 ef	551 fg	977 e	877 e	955 ef	1,314
0	0	4,000	359 b	599 c	602 de	819 cd	2,240abcd	682 cdef	942abcde	1,820abcd	1,199abcd	1,086 def	1,543
0	0	2,000	664 b	858 bc	690 cde	1,342abc	2,427abc	619 def	823 cdef	1,554abcde	1,299ab	1,244 bcde	1,712
0	0	0	582 b	684 c	563 e	849 bcd	1,513 d	388 f	451 g	894 e	828 e	818 f	1,125

[1] Applied annually.
[2] Applied first year only.

APPENDIX TABLE 29.--Residual effect of phosphorus application on dry matter yield of ladino clover grown on Wellston very fine sandy loam, Blacksburg, Va.

Treatment			Residual phase and clipping				Average yields 1959-1960	
			1959		1960			
Super-phosphate	Rock phosphate	Lime	First	Second	First	Second	First	Total
Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre
[1] 15	0	4,000	1,485 bcd	1,427 cd	1,755 cde	468 cdef	1,620 cde	2,567
[1] 30	0	4,000	2,518a	3,012a	2,576a	697ab	2,547a	4,402
[1] 60	0	4,000	2,172ab	2,136 bc	2,485a	767a	2,329a	3,530
[1] 120	0	4,000	2,147ab	2,772ab	2,237abc	775a	2,192abc	3,966
[2] 300	0	4,000	2,104abc	2,332ab	2,360ab	689ab	2,231ab	3,742
0	[2] 600	4,000	1,572 bcd	1,272 d	1,941 bcd	595 bc	1,756 bcd	2,690
0	[2] 600	2,000	1,225 de	1,215 de	1,958 bcd	558 bcd	1,591 de	2,479
0	[2] 600	0	1,077 de	699 de	1,613 de	497 cde	1,345 de	1,943
0	[2] 300	4,000	1,231 de	1,150 de	1,621 de	381 ef	1,426 de	2,192
0	[2] 300	2,000	1,380 cde	1,048 de	1,670 de	402 def	1,525 de	2,249
0	[2] 300	0	693 de	833 de	1,354 e	365 ef	1,023 e	1,622
0	0	4,000	854 de	653 de	1,220 ef	334 efg	1,037 e	1,530
0	0	2,000	928 de	800 de	1,274 e	309 fg	1,101 e	1,655
0	0	0	0 f	367 e	774 f	175 g	387 f	658

[1] Applied annually.
[2] Applied first year only.

APPENDIX TABLE 30.--Yield response of four legumes to phosphorus applied as rock phosphate and concentrated superphosphate to Plummer sandy loam, Tifton, Ga.

Treatment			Treatment period and dry matter yield[1]					Annual average yield	Residual phase	
Super-phosphate[1]	Rock[2]	Lime[2]	1953	1954	1955	1956	1957		1959	1960
Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre
SWEET CLOVER										
15	0	950	869	1,380	348	830	478	781	--	--
30	0	950	1,747	1,836	296	1,174	981	1,207	[3] 327	[3] 717
60	0	950	2,054	2,650	886	934	776	1,460	93	310
120	0	950	2,940	2,347	535	907	780	1,502	145	218
300	0	950	3,425	1,835	330	1,022	737	1,470	168	214
0	300	950	2,522	2,283	552	1,237	1,977	1,714	267	985
0	600	0	413	1,027	428	272	130	454	--	--
0	600	950	2,417	2,660	841	1,437	2,238	1,919	460	580
0	1,200	950	3,544	3,245	952	2,516	3,109	2,673	--	--
L.S.D. at 0.05...............			800	978	428	316	552	--	243	349
BIG TREFOIL										
15	0	950	--	368	151	201	1,447	542	--	--
30	0	950	--	681	420	341	2,974	1,104	[3] 2,780	[3] 2,010
60	0	950	--	1,247	552	511	3,663	1,493	1,370	453
120	0	950	--	1,332	504	623	4,066	1,631	1,826	1,757
300	0	950	--	988	314	411	2,242	989	1,130	425
0	300	950	--	651	263	347	2,569	957	1,337	791
0	600	0	--	932	279	272	3,268	1,188	--	--
0	600	950	--	1,182	695	364	2,962	1,301	1,428	766
0	1,200	950	--	1,072	404	403	3,391	1,317	--	--
L.S.D. at 0.05...............			--	483	428	316	552	445	243	349
CRIMSON CLOVER										
15	0	950	1,242	1,730	937	705	1,572	1,237	--	--
30	0	950	1,777	2,171	1,261	1,165	1,771	1,629	[3] 1,261	[3] 2,341
60	0	950	3,141	3,192	2,146	950	2,389	2,363	614	1,058
120	0	950	3,794	2,818	1,760	1,137	3,003	2,502	917	2,591
300	0	950	4,385	2,105	1,033	1,005	1,339	1,973	265	604
0	300	950	1,196	2,686	1,551	1,295	2,460	1,838	466	1,141
0	600	0	2,330	1,456	1,209	833	807	1,327	--	--
0	600	950	1,284	2,393	1,644	1,398	3,178	1,979	780	1,567
0	1,200	950	2,463	3,015	1,682	1,274	3,306	2,348	--	--
L.S.D. at 0.05...............			786	773	428	316	552	571	243	349
LADINO CLOVER										
15	0	950	133	652	185	399	826	439	--	--
30	0	950	417	1,676	416	872	1,665	1,009	[3] 1,045	[3] 1,113
60	0	950	1,227	2,954	883	916	2,428	1,682	269	320
120	0	950	2,206	3,006	678	1,013	2,372	1,855	1,022	1,365
300	0	950	1,991	1,507	300	764	729	1,058	111	43
0	300	950	362	2,517	400	710	1,499	1,098	206	135
0	600	0	717	1,809	689	690	1,623	1,106	--	--
0	600	950	341	2,211	640	1,062	2,094	1,270	712	1,316
0	1,200	950	885	2,297	766	1,071	2,415	1,487	--	--
L.S.D. at 0.05...............			505	761	428	316	552	640	243	349

[1] Applied annually except for 300-lb. rate, which was applied at beginning of experiment only.
[2] Single application at beginning of experiment.
[3] Received 120 lb. of P_2O_5 from concentrated superphosphate in fall of 1958 and 1959.

APPENDIX TABLE 31.--Yield response of ladino clover to phosphorus applied as rock phosphate and concentrated superphosphate to limed Henry silt loam, Oakley, Miss.

Treatment		Treatment period						Residual phase		
Super-phosphate[1]	Rock phosphate[2]	1953	1954	1955	1956	1957	Average 1953-57	1958	1959	Average 1958-59
Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre	Lb./acre
0	0	3,149 cd	2,239 c	3,016 d	1,775 c	3,055 b	2,647	4,356a	3,030 b	3,693
15	0	3,126 cd	2,253 c	3,303 cd	2,007 bc	3,955ab	2,929	4,295a	3,452ab	3,874
30	0	2,990 d	2,647 bc	3,577 bcd	2,324 bc	3,318ab	2,971	[3] 4,408a	3,199ab	3,804
60	0	3,745ab	3,277 b	3,626 bc	2,433 bc	3,959ab	3,408	4,079a	2,909 b	3,494
120	0	4,156a	4,036a	4,315a	3,697a	4,024ab	4,046	4,694a	4,075a	4,385
0	300	3,581 bc	2,735 bc	3,626 bc	2,138 bc	4,105a	3,237	4,202	3,779ab	3,991
0	600	3,876ab	3,399ab	4,134ab	2,545 b	4,116a	3,614	4,763	3,437ab	4,100

[1] Applied annually.
[2] Applied first year only.
[3] Single application of 120 lb. of P_2O_5 from triple superphosphate, December 1957.